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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1947 ANNUAL MEETING

AT

COLUMBIA UNIVERSITY

New York City

January 29–30–31, 1948

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of the

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AMERICAN PHYSICAL SOCIETY

1947 ANNUAL MEETING AT NEW YORK, JANUARY 29–30–31, 1948

THE **282nd meeting of the American Physical Society,** being the **1947 Annual Meeting,** will be held in New York City in the buildings of Columbia University on Thursday, Friday, and Saturday, January 29th, 30th, and 31st, 1948. This will be the fifth consecutive Annual Meeting which we shall have held at Columbia University: our members should try to realize how great is the recurrent labor thus imposed upon the Department of Physics of this University, whose situation singles it out for this great and burdensome favor to the Society. For the first time in our history, *three* of our Divisions are contributing to the programme: the Division of Electron Physics, the Division of Solid-State Physics, and the Committee on Fluid Dynamics which is by way of becoming a Division. Invited papers on the general programme are few but distinguished. The number of contributed papers is close to the record.

Hotel. The headquarters hotel is the New Yorker, at the corner of Eighth Avenue and West Thirty-fourth Street, accessible by underground passage from Pennsylvania Station. To go from it to Columbia University the most convenient way is to walk through Pennsylvania Station to the IRT subway at the east side of the station, and take a northbound train—express or local—marked BROADWAY to the 116th Street station. It is not known whether rooms will still be available when this Bulletin reaches the members, but ample notice was given in earlier announcements.

The **registration desk** will be on the ground floor of the Pupin Physics Laboratories: all members and guests are asked to register. To reach Pupin from the subway station, walk north along Broadway and turn right into the campus through the gate at 119th Street. Maps of the campus showing session rooms and luncheon places will be offered at the desk, and dinner tickets will be sold there up to 3 o'clock on Friday afternoon.

Contributed papers will be given in fifteen sessions from Thursday morning through Saturday afternoon. Those of the sessions headed "Electron Physics" were evoked in part by the summons of the Division of that name; those of the sessions headed "Solid-State" were evoked in part by the summons of the Division of Solid-State Physics; those of Session J on Thursday afternoon were evoked in the main, if not altogether, by the summons of the Committee on Fluid Dynamics.

Invited papers on the general programme comprise one by C. D. Anderson, "Cosmic rays at thirty thousand feet" at twelve noon on Thursday; one by P. M. Morse, "Plans for the Brookhaven National Laboratory," on Friday afternoon; one by Julian Schwinger, "Theoretical foundations of quantum electrodynamics," and one by H. C. Pollock, "Visible radiation from accelerated electrons in the 70-Mev synchrotron," both on Saturday morning. On Friday afternoon James Franck will give a memorial address in honor of Max Planck, and on Friday evening after the dinner R. F. Bacher will speak on "The physicist and the future development of atomic energy."

The **retiring presidential address** of L. A. DuBridge will be given on Friday afternoon at

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two under the title "Electron emission from metal surfaces: a review."

The **Committee on Fluid Dynamics** has arranged in conjunction with the Institute of Aeronautical Sciences two symposia, one on "Upper-atmosphere research" in the North Ballroom of the Hotel Astor (Times Square) on Thursday morning, the other on "Physics of rarefied gases" in Pupin 301 on Friday morning; contributed papers in this field will be given in Pupin 301 on Friday afternoon.

The programme of the **Division of Solid-State Physics** consists of a symposium on Thursday morning, while contributed papers elicited in part by the summons of this Division are scheduled for Thursday afternoon, Friday morning, and Saturday morning—all in Horace Mann Auditorium.

The programme of the **Division of Electron Physics** consists of twelve invited papers distributed between Friday morning, Saturday morning, and Saturday afternoon, all in Havemeyer 309; and the contributed papers assigned to Thursday morning in Pupin 301.

Of the **other sessions,** two on Thursday are allotted to cosmic rays and counters; one on Thursday afternoon to optics taken in the broadest possible sense; session S on Saturday morning to low temperature physics and isotope separation; session Z on Saturday afternoon to theoretical physics; sessions on Thursday, Friday, and Saturday to nuclear physics apart from cosmic rays. The difficulties of classification are becoming insurmountable in several places, e.g., in deciding whether papers on nuclear resonance should go to nuclear physics or solid-state physics, whether papers on microwave spectroscopy should go to nuclear physics or molecular physics, whether papers on electrical phenomena in solids should go to solid-state physics or electron-physics. Transcending these is the impossibility of arranging 190-odd papers in six half-days so that no member shall desire to hear two or more papers simultaneously given.

The **Business Session of the American Physical Society** will be held on Friday afternoon at 4:15 in the McMillan Theatre.

The **dinner of the American Physical Society** will be held in the Grand Ballroom of the Hotel New Yorker at seven o'clock on Friday evening. The price of $5.00 will startle our members, but the members of many other societies have learned to take such prices in their stride, and it is hoped that the members of our Society will adapt themselves. The Columbia University Faculty Club being now much too small, and the 1947 experiment of a divided dinner having proved unpopular, there is no other recourse excepting that of abandoning the New York dinner altogether. Members and guests should *immediately* send in the form printed on the inside back cover page, unless they have already notified this office of their intention to come.

The **Council of the American Physical Society** will meet at a time and place of which its members will be notified.

The American Institute of Physics will operate a **Placement Service Register** in Room 329 in Pupin Physics Laboratories at the time of this meeting. To facilitate the scheduling of interviews, employers and applicants should report to the Register immediately on arrival. Descriptions of open positions and requests for registration forms should be sent to the Institute, 57 East 55 Street, New York 22, New York.

The **next meeting of the Society** will be held at Washington on Thursday, Friday, and Saturday, April 29, 30, and May 1, 1948. The official hotels are the Raleigh, Shoreham, Wardman Park, Washington, and Willard. It is not too early to write to these hotels for rooms, mentioning the name of this Society.

General Rules Relating to Papers

The By-Laws of the Society stipulate that no contributed paper may be accepted for presentation at any meeting of the Society unless the title and an abstract of the paper are delivered to the office of the Society not later than the closing date stated in the printed call for the meeting.

The time allowed for the oral presentation of a contributed paper is ten minutes at most.

When two or more papers are contributed by the same member, all but one are placed on the "supplementary programme." (A paper by two

or more members is credited to the one first named in its by-line.) For each paper on this programme a session is indicated at the end of which it may be offered: but the presiding officer of the session may require that it be given in shortened form or may read it by title.

Titles and abstracts of the papers to be presented at the 1947 Annual Meeting are given in the following pages. Proofs of the abstracts have not been submitted to the authors, and the proof reading is always cursory because of the need for haste: but the authors have opportunity to correct their proofs before the abstracts appear in the Physical Review.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

PROGRAMME

THURSDAY MORNING AT 9:00

North Ballroom, Hotel Astor

(H. L. DRYDEN presiding)

Joint Symposium of the Fluid Dynamics Committee and the Institute of Aeronautical Sciences

Upper-Atmosphere Research

A1. Upper-Atmosphere Temperatures from Remote Sound Measurements. E. F. COX, *Naval Ordnance Laboratory.* (45 min.)

A2. Heat Transfer to Bodies Traveling at High Speed in the Upper Atmosphere. J. R. STALDER AND DAVID JUKOFF, *Ames Aeronautical Laboratory.* (45 min.)

A3. Wind Tunnel Testing Problem in Super-Aerodynamics. HSUE-SHIEN TSIEN, *Massachusetts Institute of Technology.* (45 min.)

THURSDAY MORNING AT 9:45

Horace Mann Auditorium

(L. A. DUBRIDGE presiding)

Symposium of the Division of Solid-State Physics

B1. Crystallographic Factors in Lattice Imperfections. R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*

B2. Basic Principles of Operation of Crystal Counters. FREDERICK SEITZ, *Carnegie Institute of Technology.*

B3. Ferromagnetic Domains. H. J. WILLIAMS, *Bell Telephone Laboratories.*

B4. (Title to be announced.) J. L. SNOEK, *Philips Research Laboratories, Eindhoven, Holland.*

THURSDAY MORNING AT 10:00

McMillin Theatre

(W. F. G. SWANN presiding)

Cosmic Rays and Counters

C1. New Experiments Concerning the Surplus Gamma-Radiation from Rocks. VICTOR FRANCIS HESS AND J. DONALD ROLL, S.J., *Fordham University.*—Two experiments were performed to determine if the surplus gamma-radiation from granite, observed by one of the authors (V.F.H.), could be due to cosmic rays inducing fission of uranium or thorium or artificial radioactivity within the granite. *A.* A large sample of dunite, an ultrabasic rock

which is practically free of radioactive elements, was placed in an iron house surrounding an ionization meter. The ionization observed with the dunite was practically zero. *B*. The iron house was then filled with crushed granite, first at Fordham, then in an underground station where the cosmic-ray intensity was reduced to a few percent of the surface value. No difference in ionization due to the granite was observed at the two levels. Thus the surplus gamma-radiation cannot be ascribed to the effect of cosmic radiation on the granite. Since E. Gleditsch and T. Gráf have recently published a new determination of the intensity of gamma-radiation from potassium which is considerably higher than other values found in the literature, further experiments are necessary before it can be decided whether the surplus radiation is due to a previously underestimated intensity of gamma-rays from potassium or to some unknown source.

C2. The Nature of the Primary Cosmic Radiation.* MARCEL SCHEIN, *University of Chicago*.—The penetration and shower production of cosmic-ray particles was investigated close to the top of the atmosphere at a geomagnetic latitude of 52° North. It was found that most of the particles from the vertical are capable of traversing very large thicknesses of lead and, hence, they cannot consist of electrons. A very large East-West asymmetry of the hard component was recently observed by the author in collaboration with V. H. Yngve and H. L. Kraybill in a B-29 plane at an altitude of 35,000 feet. This can only be explained if we assume that a considerable fraction of the primaries is positively charged. Most of the primary particles should carry a single charge since there has been no marked latitude effect observed on cosmic-ray phenomena corresponding to an energy range around 10^{11} ev. All the above-mentioned facts strongly indicate that the large majority of the primary cosmic rays must consist of protons.

* This research was supported in part by the U. S. Navy.

C3. Specific Primary Ionization in Hydrogen by a Coincidence-Counter Method.* FRANK L. HEREFORD, *Bartol Research Foundation*.—Considerable discrepancies exist in the comparison of the experimentally and theoretically determined variation of the primary ionization with energy of incident particles. Bethe's theory predicts a logarithmic increase in ionization above a certain minimum point in the curve, which hitherto has not been confirmed.[1] With a coincidence train containing three high pressure counters and one low pressure counter this minimum was recently observed[2] in a helium-butane mixture. The experiment has been repeated using a low pressure hydrogen counter, results again confirming the predicted minimum and subsequent increase of ionization with energy. More elaborate path-length calculations[3] have made possible a more precise determination of ionization by sea-level cosmic radiation than was previously possible.[2] The counter method avoids the uncertainty inherent in cloud-chamber measurements in distinguishing between the primary and total ionization. The only assumption involved is that creation of a single ion pair will discharge the counter with unit probability.

* Supported by the Office of Naval Research.
[1] M. G. E. Cosyns, Nature **139**, 802 (1937); W. E. Hazen, Phys. Rev. **63**, 107 (1943).
[2] F. L. Hereford, Phys. Rev. **72**, 982 (1947).
[3] See abstract RT2, E. E. Witmer and M. A. Pomerantz.

C4. Detection of Ionizing Radiation by Ultra High Frequency Gas-Discharge Counters.* SANBORN C. BROWN, *Massachusetts Institute of Technology*.—Characteristics of a coaxial mode cavity resonator as a gamma-ray counter making use of a 3000-mc gas discharge will be described. The breakdown of a discharge in gases at these frequencies does not depend upon secondary effects, and since the breakdown field is not controlled by positive ions, shorter breakdown times and shorter resolving times than of a Geiger-Müller counter are realized. The u.h.f. discharges show ambipolar diffusion as the controlling factor in loss of electrons, and a d.c. clearing field is superimposed on the a.c. field to eliminate electrons most rapidly. A quenching agent is present to suppress electron emission from positive-ion bombardment of the walls. The discharge is quenched by pulsing the magnetron power source down by suitable electronic circuits. The plateau characteristics are similar to those found with a Geiger-Müller counter. The sensitivity can be made the same as that of a Geiger-Müller counter of similar geometry. The minimum resolving time achieved is 5 microseconds. Pulse rise times measured by delay-line clipping methods show the pulse rising from 0.05 volt to 3 volts in 6×10^{-9} second.

* This work was supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

C5. A Pulse Transformer Technique for Application to Coincidence Counting. B. G. FARLEY, *Yale University*.—For amplitude-type coincidence discrimination, differentiating transformer coupling networks offer certain advantages in pulse amplification and shaping, particularly because they allow the application of positive pulses to all grids with little d.c. level change if grid current is drawn. By designing transformers with low mutual and leakage inductances and resistance, pulses of the order of 100-volt height and 0.1-microsecond width at the base are easily obtained with power video tubes. One method of discrimination is to connect the outputs of the final transformers in each channel in parallel. The discrimination time of such a circuit with proportional counters is in the vicinity of 10^{-7} sec. to 10^{-8} sec., the exact time depending on the conditions of variability of the pulses and amount of noise. With identically recurring, artificial pulses the discrimination is, of course, considerably better.

* Assisted by the Office of Naval Research.

C6. High Efficiency, High Speed Scintillation Counters for Beta- and Gamma-Rays. MARTIN DEUTSCH. *Massachusetts Institute of Technology*.—Counters that, according to Kallman,[1] use naphthalene screens and photo-multiplier detection have been investigated with the following results:

Substantially every electron is counted if it spends sufficient energy in the screen, namely about 0.15 Mev at room temperature or 0.05 Mev at dry-ice temperature. Screens several cm thick have been used giving an efficiency of 20 percent for counting 1.2-Mev gamma-rays and even higher for softer gamma-rays. Energies of beta- and gamma-rays can be determined from bias curves with accuracy comparable to ordinary absorption measurements. Coincidence resolving times at least as short as 0.1 microsecond can be used without measurable losses. No marked difference in performance is found between ordinary "moth flakes" and so-called chemically pure naphthalene. Large clear lumps can be obtained easily by cooling from the melt. Solid benzene performs as well as naphthalene. Solid bromobenzene gives smaller pulses but may be useful because of its higher density. α- and β-bromonaphthalene and 1,4-dibromobenzene gave no useful pulses. This work was supported in part by the Office of Naval Research.

[1] H. Kallman, Natur und Technik (July 1947).

C7. Characteristics of Geiger Counters Filled with Lead Tetramethyl Vapor. C. L. MEAKER, C. S. WU, AND L. J. RAINWATER, *Columbia University.*—Geiger Counters filled with tetramethyl lead vapor have been thoroughly investigated. This is a self-quenching gas which exhibits a satisfactory plateau over wide voltage ranges irrespective of the material of the cathode cylinder. The useful life of the counter under constant high counting rate was found to be more than 10^9 counts in all counters tested. The efficiency for detecting electrons *vs.* vapor pressure has been studied. At a pressure as low as 14 mm of Hg, an ordinary standard thin-wall silvered counter counts approximately 100 percent of the composite beta-particles from phosphorus P^{32}. Because of this low gas pressure, the dead time of counters filled with lead tetramethyl vapor is much less than counters filled with the mixture of argon and alcohol. Typical values for the counter dead time are near 5×10^{-5} sec. Counters filled with this vapor are particularly useful for measurements involving very high counting rates. The effect of the time constants of the amplifier circuit on the determination of dead time of a counter will be discussed.

C8. High Pressure Cloud Chamber with Intense Magnetic Field. T. H. JOHNSON AND R. P. SHUTT, *Brookhaven National Laboratory.*—The paper describes the design of a high pressure cloud chamber suitable for photographing a considerable number of mesons decaying in the gas. The probability of photographing a meson at the end of its range is proportional to the stopping power of the gas, to the sensitive time, to the window area, and to the average range. The sensitive time, determined by diffusion, is proportional to the pressure, p. Thus the probability factor for the chamber is proportional to p^2. The magnetic field required to offset multiple scattering in the determination of meson momentum must be increased approximately at $p^{\frac{1}{2}}$. In 300 atmospheres of argon the momentum of a particle with 10-cm residual range can be determined in a field of 30,000 gauss with 10 percent accuracy.

The chamber design incorporates coils external to a nonmagnetic pressure cylinder which will produce a field of this intensity when excited by four Navy mine sweep generators delivering 2160 kw intermittently. A massive rectangular yoke of iron holds the pole pieces together against the high internal pressure. Stereo photographs are made through small windows of thick glass and a column of water inside the pressure volume. The cloud chamber is hydrostatically supported by oil contained within the pressure cylinder.

C9. Probability of Meson Track Endings in a High Pressure Cloud Chamber. RICHARD W. SAFFORD, *Brookhaven National Laboratory.*—Calculations have been made of the probability of obtaining meson track endings in a proposed high pressure cloud chamber with 200-atmosphere pressure of argon and a magnetic field of 30,000 gauss, relative to a cloud chamber at atmospheric pressure and no magnetic field. The paths of mesons in the magnetic field were calculated taking into account Bethe-Bloch energy losses in the various absorbing materials (iron, oil, lead, and argon at 200 atmospheres) for a range of incidence angles and energies. Scattering was not considered. Results for cloud chambers of the same dimensions, normalizing for the probability in a cloud chamber at atmospheric pressure with no magnetic field, were as follows: cloud chamber at atmospheric pressure, $P=1$; high pressure cloud chamber with no magnetic field, $P=200$; high pressure cloud chamber with magnetic field, $P=450$; high pressure cloud chamber with magnetic field surrounded by 20 cm of lead, $P=350$. The cloud chambers were considered biased to the same energy range by lead. Probabilities are given for the same sensitivity time.

THURSDAY AT 12:00

McMillin Theatre

(W. F. G. SWANN presiding)

Invited Paper

C10. Cosmic-Ray Effects at Thirty Thousand Feet. C. D. ANDERSON, *California Institute of Technology.* (40 min.)

THURSDAY MORNING AT 10:00

Havemeyer 309

(M. W. WHITE presiding)

Diverse Topics of Nuclear Physics

D1. Gamma-Rays from Alpha-Particle Reactions. DAVID E. ALBURGER, *Yale University.**—Energies of gamma-rays from sodium, magnesium, aluminum, silicon, phosphorus, and sulfur targets under cyclotron bombardment by 7-Mev alpha-particles have been measured by observing the maximum range of Compton-recoil electrons in aluminum. Two beta-ray counters were arranged on a line with the target so that electrons in the forward direction produced in the end wall of the first counter could pass through both counters giving coincidences. The thickness of aluminum absorber placed between the counters at which the counts were reduced to the random coincidence rate gave the maximum range of the electrons. Using the modified Feather relation to compute the recoil-electron energy and adding the energy of the back-scattered gamma-ray the following gamma-rays were found: sodium, 2.75±0.25 Mev; magnesium, 1.81±0.18 Mev and 4.3±0.3 Mev with an intensity ratio of 3 to 1; aluminum, 3.5±0.3 Mev; silicon, 2.3±0.2 Mev; phosphorus, 2.55±0.25 Mev and 4.1±0.4 Mev with an intensity ratio of 8 to 1; sulfur, 2.4±0.3 Mev. Comparison of these with the Q-values of proton groups in the corresponding αp reactions shows that in cases where correlation can be made the transition from the second excited state to ground in the product nucleus is favored.

* Assisted by the Office of Naval Research.

D2. Proton Groups from Deuteron Bombardment of Sulfur. PERRY W. DAVISON, *Yale University.**—Bombardment of H_2S gas with 3.3-Mev deuterons yields eight groups of protons. The possibility that the two shortest-range groups are due to air (N_2 and O_2) contamination has been ruled out on the basis of yield and variation of yield with deuteron energy. On the same basis the longest range group is believed due to nitrogen. All except this longest-range group are assigned to the reaction $S^{32}(dp)S^{33}$, S^{32} being the predominant isotope. The Q-values calculated are given in the following table.

Q in Mev	Level in Mev	Relative yield	Spacing in Mev
Q_0 6.50	0.00	1	0.98
Q_1 5.52	0.98	1/2	0.99
Q_2 4.61	1.89	3	1.05
Q_3 3.56	2.94	35	0.90
Q_4 2.66	3.84	43	0.92
Q_5 1.74	4.76	120	0.92
Q_6 0.82	5.68	350	

* Assisted by the Office of Naval Research.

D3. Energy Levels of A^{41}. ERNEST POLLARD AND PERRY W. DAVISON,* *Yale University.*—Argon gas has been bombarded by 3.4-Mev deuterons, and the protons emitted in the $A^{40}(dp)A^{41}$ reaction by absorption in aluminum were observed by use of a double coincidence method. Eight groups of protons are observed of which two are probably due to slight contamination by air and a third is possibly so explained. The remaining groups can be assigned to levels in the A^{41} nucleus. The Q-values in Mev, relative yields, and spacings are listed.

Q in Mev	Level spacing (Mev)	Intensity
Q_0 3.82		1
Q_1 3.19	0.63	0.7
Q_2 2.65	0.54	4
Q_3 1.97	0.68	1
Q_4 1.66	0.31	1 (? O_2)
Q_5 0.95	0.71	8

* Assisted by the Office of Naval Research.

D4. Proton-Proton Scattering at 2.4 and 3.0 Mev. WILLIAM SLEATOR, JR., J. M. BLAIR, E. E. LAMPI, AND J. H. WILLIAMS, *University of Minnesota.*—The differential proton-proton scattering cross section has been measured at 2.4 and 3.0 Mev at angles from 8° to 45° by a method similar to that of Herb, Kerst, Parkinson, and Plain.[1] Protons from the Minnesota Van de Graaff generator reached the scattering chamber (inside diameter 43 cm) through a collimator of half-angular spread 0.5° and entered a Faraday cage. Scattered protons were observed with two proportional counters, one fixed for monitoring, and the other movable in angle. The slit system defining the scattering volume had a half-angular aperture of 0.66° for measurements below 15° and 1.23° for those above 15°. At 15° both analyzers were used to check geometrical factors. The observed scattering cross sections, uncorrected for finite geometry, are given in the table. The over-all probable error is approximately 2 percent. The values at 2.4 Mev (above 15°) are on the average larger than those of HKPP by about 2.9 percent. Measurements at higher energies are in progress.

Proton-proton cross section per unit solid angle (in barns)

Angle	8°	10°	12.5°	15°	17.5°	20°	25°	30°	35°	40°	45°
2.4 Mev	8.24	3.23	1.41	0.820	.635	.575	.540	.536	.522	.483	.459
3.0 Mev	5.22	2.10	1.00	0.657	.560	.512	.499	.484	.462	.441	.413

[1] Herb, Kerst, Parkinson, and Plain, Phys. Rev. **55**, 998 (1939).

D5. The Charge Distribution in Nuclei and the Scattering of High Energy Electrons. M. E. ROSE, *Clinton National Laboratory.*—The possibility of determining the shape of the charge distribution in nuclei as well as nuclear

radii by the scattering of high energy electrons has been investigated. Assuming a Coulomb interaction between protonic charge elements and electron, the nuclear form factor can be directly related to the ratio of observed to point charge (Mott) scattering. While total cross sections are essentially unchanged, the cross section for large momentum losses, such as would occur for about 50-Mev electrons elastically scattered through angles of order $\pi/2$, is reduced from the Mott value by readily observable amounts. The case of scattering in deuterium has been considered in view of the possibility of a direct determination of the deuteron wave function apart from quadripole moment effects. Competition from scattering with nuclear excitation and disintegration, atomic ionization, and bremsstrahlung are not serious provided that the electron energy is in the neighborhood of 50 Mev, the scattering angles of order $\pi/2$ and the electrons observed in the scattering experiment are scattered with small energy loss.

D6. Sensitivity of Proton-Proton Scattering to Potentials at Different Distances. G. BREIT, A. A. BROYLES, AND M. H. HULL, *Yale University.**—The small changes in potential energy δV are taken to be in small intervals ΔR at distance R. Estimates are made for the combined effect of $q=(\delta V)\Delta R$ for $R\ mc^2/e^2=3$, 5 and simultaneous change in depth δD of short-range (e^2/mc^2) well. Similarly the combined effect of q, δD and change in range is studied. For an assumed $R\ mc^2/e^2=5$, measurement of scattering with an accuracy of 1 percent determines q with an accuracy approaching 1 kev through a distance e^2/mc^2. The energy region 200–600 kev is found to have special merits for the determination of the shape of the potential energy curve.

* Assisted by the U. S. Navy.

D7. Inelastic Scattering of Protons by Light Nuclei. KENNETH E. DAVIS AND EVERETT M. HAFNER, *University of Rochester.*—Energy states of light nuclei can be found by studying inelastically scattered protons by use of incident beams of several Mev. The method was introduced by Wilkins[1] and developed by others. We have attempted to improve further the sensitivity and resolution of the experiment. An incident beam of 7.0 Mev is defined to 2 percent by a slit system in the cyclotron fringing field. The thin solid target is oriented at an angle that is favorable from the standpoint of homogeneity of scattered proton groups. A fixed scattering angle of 35 degrees is used as a compromise between excessive Coulomb scattering at lower angles and loss of resolution, due to uneven targets, at high angles. Energies are resolved by 180-degree focusing in a magnetic field, and protons are detected in Eastman NTA photographic plates. Energy intervals of several Mev in the nuclear spectra are covered in each measurement. An interesting result obtained with this equipment is a level that has been tentatively assigned to Be^9, appearing at 2.42 Mev above the ground state (0.79 Mev above the dissociation energy) and having a width less than 0.15 Mev. Other results for several light nuclei will be discussed.

[1] T. R. Wilkins, Phys. Rev. 60, 365 (1941).

D8. The Reaction $He^3(n, p)H^3$ and the Neutrino Mass. D. J. HUGHES AND C. EGGLER, *Argonne National Laboratory.*—The mass of the neutrino can be measured by a careful determination of the Q-value for an (n, p) reaction if the resulting β-emitter has an accurately known end point. We have determined the Q-values for the reactions $N^{14}(n, p)C^{14}$ and $He^3(n, p)H^3$ from the proton ranges in a cloud chamber. The hitherto unobserved helium reaction was found by use of pile neutrons and helium containing about 10^{-3} percent He^3. From the measured mean ranges and the stopping power of the chamber, the range in air of the N^{14} proton is 0.991 cm, and that of the He^3 proton is 0.980 cm. The range results, together with the range energy curve given by Livingston and Bethe, give the following values for the proton energy and the neutrino mass:

$$He^3;\quad E_p=552\text{ kev};\quad \mu c^2=4\pm25\text{ kev},$$
$$N^{14};\quad E_p=557\text{ kev};\quad \mu c^2=1\pm25\text{ kev}.$$

By far the largest part of the error results from the uncertainty in the range energy curve. However, the relative mass of the neutrino in the two cases is known much better; actually the experiment shows that the mass of the neutrino for H^3 and C^{14} is the same within about 5 kev.

D9. A New Table of Absolute Nuclear Abundances. HARRISON BROWN, *University of Chicago.*—The only table of absolute nuclear abundances heretofore available has been that compiled by V. M. Goldschmidt,[1] in 1937. Since that time developments have warranted a re-evaluation of existing information. Following the method of Goldschmidt, the two main sources of data utilized in compiling the new table were stellar spectra and meteorites. Stellar spectra data were used in order to evaluate the abundances of very light elements together with elements which clearly would have been fractionated from less volatile constituents during the process of planet formation. Meteoritic abundances have been used in all other cases. The new table possesses the same general characteristics as Goldschmidt's table, but significant changes have resulted from the following developments: (1) more extensive stellar data; (2) more precise linking of stellar abundances to meteoritic abundances; (3) more accurate evaluation of the ratio of metal to silicate phase in meteorites and in the minor planets; (4) statistical evaluation of standard deviations of elemental abundances in meteorites; (5) development of a general theoretical background guiding the use of meteoritic data in the compilation of such a table.

[1] V. M. Goldschmidt, *Geochemische Verteilungsgesetze der Elemente* (Oslo, 1938), Chapter IX, "Die Mengenverhältnisse der Elemente und der Atom-Arten."

D10. Nuclear Magnetic Moments as Integral Multiples of a Natural Unit. ENOS E. WITMER, *University of Pennsylvania.*—A study of the most accurately measured magnetic moments of nuclei appears to support the conclusion that they are either exactly or very nearly *integral multiples of* $\mu_N/672$, where μ_N is a nuclear magneton. This conclusion is based on the accurate g-values or ratios of g-values for H^1, H^2, H^3, Li^6, Tl^{205}, and the difference of the g-values for Ba^{135} and Ba^{137}. For H^1 the magnetic moment is taken to be

1876 $\mu_N/672$. This is in general accord with a previous statement by the writer,[1] but the natural unit here is only one-fourth as large as in that statement. It is in accord with and helps to explain the fact that for the experimental nuclear g-values, $84g$ is frequently, but not always, very close to an integer.

[1] Enos E. Witmer, Proc. Nat. Acad. Sci. **32**, 283 (1946).

D11. The Hyperfine Structure of Hydrogen and Deuterium. JOHN E. NAFE AND EDWARD B. NELSON, *Columbia University.*—The atomic-beam magnetic resonance method has been applied to measure the h.f.s. separation of the ground state of H and D by observing frequencies of the r-f field required to induce transitions among certain of the magnetic levels of the h.f.s. multiplets in magnetic fields of the order of 1 gauss. The resonance minima were of the theoretical width for transitions which are field independent in the first order. For hydrogen we find $\nu_H = 1420.410 \pm 0.006$ Mc and for deuterium $\nu_D = 327.384 \pm 0.003$ Mc. The ratio $\nu_H/\nu_D = 4.33867 \pm 0.00004$. The h.f.s. separations ν_H and ν_D, and their ratio ν_H/ν_D may be calculated from known values of the magnetic moment of the proton, μ_p, the magnetic moment of the deuteron, μ_d, and the ratio μ_p/μ_d. The measured ν_H and ν_D are larger than the calculated values by 0.25 percent and 0.26 percent, respectively. The ratio of the measured h.f.s. separations is 0.017 percent lower than the calculated ratio. The latter discrepency is 18 times the probable error in our measurement.

D12. Effect of Large Quadrupole Interactions on Nuclear Radiofrequency Spectra at Twice Larmor Frequency. NORMAN F. RAMSEY, *Harvard University.**—The work of Feld and Lamb[1] on the effect of a nuclear electrical quadrupole moment on the radiofrequency spectrum of a diatomic molecule in a magnetic field is extended to a special case not considered by them. This is a case in which the electrical quadrupole interaction energy is so large that even in magnetic fields of several thousand gauss the magnetic interaction energies are small compared to the electrical quadrupole interaction energy. In this case it is shown theoretically that for a spin of $\frac{3}{2}$ there are certain circumstances under which the maximum of absorption will occur at double the Larmor frequency instead of at the Larmor frequency, and will have a field and molecule dependence similar in many ways to a resonance at the Larmor frequency. This result has the important implication that special care must be used in identifying the radiofrequency resonance absorption spectra or an error of a factor of two in the value of a nuclear magnetic moment can easily be made. The approximate shape and intensity of the radiofrequency absorption spectrum under these circumstances is calculated in order that a comparison of the theoretical shapes and intensities with the experimental ones can be used as a means of recognizing if an absorption is a double Larmor frequency one. This theory may be applied for example to identify the radiofrequency spectra of diatomic molecules containing Br and Cl.

* Part of this work was done at Columbia University.

D13. The Application of $Li^6(n, \alpha)$ and $B^{10}(n, \alpha)$ to Slow-Neutron Monitoring. MAURICE M. SHAPIRO AND JOHN R. BARNES, *Clinton National Laboratories.*—When slow neutrons impinge on a photographic emulsion impregnated with lithium or carbon, the yield of disintegration tracks from the $Li^6(n, \alpha)$ and $B^{10}(n, \alpha)$ reactions, respectively, is very high. Moreover, when a suitable emulsion is employed, the tracks are dense and easily observable under high power magnification. These observations suggested the applicability of the Li and B reactions to slow-neutron health monitoring. Further investigation showed that this method of monitoring is more sensitive by several orders of magnitude than the $N^{14}(n, p)$ reaction currently employed in some laboratories. For example, in the Li-loaded plates the yield of tracks from a given slow-neutron flux is about 150 times the yield of the $N^{14}(n, p)$ tracks. Furthermore, each track (produced by a triton and an alpha-particle recoiling in opposite directions) is ten times as long as, and considerably denser than, the proton track from nitrogen. Therefore, it is easier to recognize and count. With boron-loaded emulsions, the alpha-particle tracks are even more numerous although shorter than the tracks from Li. Either of these proposed techniques of slow-neutron health monitoring permits higher accuracy, while reducing enormously the time and labor consumed in microscopic counting of tracks.

THURSDAY MORNING AT 9:30

Pupin 301

(J. R. PIERCE presiding)

Electron Physics

E1. Conversion of a D.C. Motor-Generator into a Low Noise Power Amplifier. H. S. SOMMERS, JR., P. R. WEISS, AND W. HALPERN, *Rutgers University.*—Because of the need for a noise-free d.c. power source for various servo applications, such as precision control of an electromagnet or furnace, a commercial motor-generator set has been converted into a low noise power amplifier. The generator serves as the low frequency output of a wide-band negative feed-back amplifier. The high frequency output consists of a hard tube bank, in parallel with the generator, feeding

directly into the load; an inductance inserted between the generator and the load keeps the armature from shorting the hard tube output. The band width to 3-db point of a model amplifier with 100-watt d.c. output, and voltage gain of 100, extends from d.c. to 3 kc/sec. The undistorted swing is 0–100 v at d.c., drops to 1-v r.m.s. at 30 c.p.s., and then rises to 2.5-v r.m.s. at 200 c.p.s. The noise output of the generator is reduced by a factor of 5000 at d.c., 300 at 30 c.p.s., 800 at 120 c.p.s., and finally unity at 8 kc/sec. This amplifier, which has been used in a magnet current servo that reduced peak-to-peak field fluctuations at all frequencies to less than 10^{-5} times the d.c. field, is being directly scaled to excite a 40-kw magnet.

E2. Electron Optical "Schlieren" Effect. L. MARTON, *National Bureau of Standards.*—In close analogy to the light optical "Schlieren" effect (sometimes called Töppler's shadow method) there exists an electron optical effect of similar nature. For its observation an image of a point electron source was produced, by means of a magnetic lens, on a center stop. At about half the distance between source and lens a magnetized recording wire was placed. In a conjugate plane wire proper focusing a "Schlieren" image of the magnetic field surrounding the recording wire was observed. Experiments are being carried out for practical application of this effect to a quantitative measurement of the field distribution on recording wires, to studies of field distribution from ferromagnetic domains, to studies of space charge distribution, and to investigations of electromagnetic field distribution of standing waves, of cavity resonators, of wave guides, et cetera. Results of measurements on magnetized wires will be shown.

E3. Application of the Electron Optical "Schlieren" Effect. D. L. REVERDIN, L. MARTON, AND S. H. LACHENBRUCH, *National Bureau of Standards.*—As an application of "Schlieren" optics, the radial change of index of refraction of a thin electron beam can be made visible by observing the "Schlieren" pattern. This is done by placing the beam perpendicular to the path of another electron beam. By this means information regarding either the radial potential distribution or the radial space charge distribution of the thin beam can be obtained. The potential distribution of a homogeneously distributed electron beam of circular cross section which acts as a cylindrical beam has been obtained, and the focal length for paraxial rays has been calculated. For such a space charge "lens" beam of 50 microamperes and 5000-volt accelerating potential, the calculations give, as a first approximation, a deflection sufficient for the "Schlieren" observation. The same experiment can also be studied for a more general space charge distribution, such as an electron cloud produced by a heated filament. Another application is the dispersion of an electron beam by a standing microwave field inside a wave guide. The deflection of 5000-volt electrons in a microwave field of 100 volt/cm is adequate for "Schlieren" observation.

E4. Electron Motion in Deflecting Field of Magnetic Dipole. S. H. LACHENBRUCH, *National Bureau of Standards* (Introduced by Dr. L. Marton).—After a brief outline of their derivation, the equations and graphs of the trajectories of electrons moving in the meridional plane of a magnetic dipole field under various conditions are shown, their properties discussed, and the results interpreted. Application of the equations of motion to the inverse-cube field distribution of a short dipole yields a differential equation whose exact solution is given in terms of elliptic integrals. When the distance unit is normalized, this trajectory equation involves a single parameter, B, into which are lumped all given conditions (dipole moment, permeability, electron energy, and initial direction of motion). For attracting fields a critical value of B is found, at which the form of the trajectory is radically altered. As the dipole strength approaches the critical value, the deflection angle increases rapidly and the trajectory approaches a spiral having as asymptote a circle about the dipole. Beyond this critical condition the electrons execute a small loop near the dipole and are thereafter repelled. The critical value is described numerically in terms of actual conditions, and the property is interpreted both as a practical limitation and as one to be utilized.

E5. A Study of Cathode Behavior in the Inert Gases as Applied to Minimum Sparking Potentials.* HAROLD JACOBS AND ARMAND P. LAROCQUE, *Sylvania.*—The minimum sparking potentials, V_{sm}, are determined for barium magnesium, and aluminum in the five inert gases and are found to be as follows.

	Helium	Neon	Argon	Krypton	Xenon
Barium	157	129	94	104	83
Magnesium	160	150	123	115	120
Aluminum	189	160	154	135	150

It is shown that, in general, the V_{sm} tends to decrease with decreasing work function, ϕ, of the surface. The second Townsend coefficient, γ, is shown to decrease with increasing F/P in the region studied, with the exception of helium. At a constant F/P, γ tends to decrease with increasing ϕ in all cases studied.

* This work was undertaken in joint cooperation of the Applied Physics Laboratory of Johns Hopkins University and by the United States Navy.

E6. Thermionic Emission of Oxide-Coated Filaments.* HAROLD JACOBS, GEORGE HEES, AND WALTER CROSSLEY, *Sylvania.*—The emission of oxide-coated filaments on different alloys (Ni, B-Ni, Ba-Ni, Co-Ni, Pt-Ni, V-Ni, tensite) was measured over a period of 500 hours. An empirical emission equation was used instead of Richardson's equation and was found to be as accurate and more simple to use.

$$I_0 = A' \exp(-e\psi/kT).$$

It was found that A' and ψ varied over life such that, $\log A' = K\psi + B$, K and B being constants. The total emission at 800°K was determined and found to be affected by the solute element or elements.

* This work was undertaken in cooperation with the United States Army Signal Corps Engineering Laboratories.

E7. Decay of Thermionic Emission of Barium-Strontium Oxide Cathodes during Space-Charge-Limited Operation. W. E. DANFORTH AND W. E. RAMSEY, *Bartol Research Foundation.*—By means of a "feeler pulse," applied at a known and variable time after the application of anode voltage (of a value where the operation is space charge limited), the variation of a cathode's intrinsic capacity to emit has been briefly studied. The circuit for accomplishing this will be described. It is found, as would be expected, that a relatively small space-charge-limited current can result in reduction of intrinsic emitting capacity, even though, by virtue of the space-charge limitation, this current remains constant in time. Results will be described of studies of decay of emission-limited current, showing that the decay pattern is not constant in a given tube, but may in certain cases be absent initially and develop during operation. In agreement with others, it is found that, in general, a decay curve cannot, over the whole range, be described by a constant plus one exponential. At least two exponentials are required and involve time constants, to quote a typical example at 900°C of 1.5×10^{-5} second and 5×10^{-4} second. This work was done under OSRD and is now in the province of Bureau of Ships.

E8. Anomalies in the Initiation of Cold-Cathode Discharges. JEROME ROTHSTEIN, *Evans Signal Laboratory.*—Life testing several hundred cold-cathode, triggered modulator tubes, constructed in this laboratory, disclosed several interesting anomalies in the initiation of the discharge. In accordance with their effect on output current pulse on a synchroscope screen, they were classified as amplitude jitter, time jitter, and pulse distortion. The first is tube drop fluctuation, the second fluctuation in time of onset of the main discharge relative to the trigger pulse. This fluctuation, usually a few tenths of a microsecond, was superimposed on a secular delay of several microseconds. Distortion was mainly of three kinds, the first a gradual increase followed by a sudden jump to near normal current. The second consisted in a rise to about half-value for about half the pulse, normal value thereafter. The third was pronounced broadening and flattening of the entire pulse. Distortion, jitter, and growth in secular delay were usually associated, became more pronounced with age, were exaggerated at lower operating voltages, and seem to be intimately connected with the state of the cathode and the glow-arc transition mechanism.

E9. Results and Semitheoretical Calculations in Microwave Breakdown.[1] D. Q. POSIN, *Massachusetts Institute of Technology and North Dakota State College.**—A considerable number of experimental results were obtained revealing the dependence of electrical breakdown at microwave frequencies on a number of parameters such as pressure of gas and width of breakdown gap; also a semitheoretical formulation was established for sparking field strength, by using certain known ionization functions and certain assumed ones. In addition, the effect of an external magnetic field in facilitating breakdown within a wave guide was studied for the case of 3-cm waves and explanations of the effect have been considered which tend to indicate the change in the power-carrying capacity of a given wave guide when placed in an external magnetic field. Calculations have been made of the equivalent rectangular pulse width for actual trapezoidal pulse of the same height, by using the ionization theory mentioned above.

[1] The experimental work is based on research done for the Office of Scientific Research and Development under Contract with the Massachusetts Institute of Technology. A number of the calculations have been performed at North Dakota State College.

* Now at the Department of Physics, North Dakota State College.

E10. Measurements of Breakdown in Low Pressure Helium at Microwave Frequencies.* MELVIN A. HERLIN AND SANBORN C. BROWN, *Massachusetts Institute of Technology.*—An electric field of sufficiently high frequency applied to electrons in a gas may deliver energy to the electrons without imparting to them any continuous drift motion in the field direction. The criterion for breakdown of a low pressure noble gas at microwave frequencies is therefore that ionization by collision of electrons with neutral gas molecules replace loss by diffusion to the walls of the discharge tube. This condition is mathematically expressed as the solution of a simple boundary value problem which has been checked experimentally. This breakdown principle is applied to converting microwave breakdown measurements into measurements of ionization rates as a function of the electric field strength and frequency. Experimental results will be presented and their relationship to the usual d.c. first Townsend coefficient will be explained.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

E11. Electric Fields in the Cathode Dark Space of an Abnormal Hydrogen Discharge. S. V. GALGINAITIS,* *University of Wisconsin.*—By measuring the magnitude of the Stark effect of the H gamma-line emitted from the cathode dark space of a hydrogen discharge, the course of the electric field as a function of distance from the cathode was obtained. A water-cooled aluminum cathode was used, and the current densities were as high as 1.50 amp./cm^2. For a given current, the field strength was greatest at the surface of the cathode, and decreased uniformly with distance to a zero value near the boundary of the negative glow. However, the length of the region of the cathode fall did not coincide with the visual length of the cathode dark space, since while the visual dark space seems to shrink with increasing current density, the spectrograms showed that the length of the region of the cathode fall increases with increasing current density. In the range of currents used, the field at the surface of the cathode increased with increasing current density.

* Now at the University of Louisville.

E12. Imprisonment of Resonance Radiation in Gas Discharges. T. HOLSTEIN, *Westinghouse Research Laboratories.*—When an excited gas atom makes an optical transition to the ground state, the emitted resonance line is highly absorbable by normal atoms of the gas. Under suitable conditions, as is shown in a previous paper,[1] the resultant imprisonment of radiation may cut down the

radiative loss of atomic excitation by an order of magnitude. In gas discharges at low or intermediate pressures ($\gtrsim$1 mm), the additional processes which affect the concentration of excited atoms, n_r, are, primarily, excitation and de-excitation collisions of electrons with normal and excited atoms, respectively. Amplifying the treatment of the above quoted paper to include these collision processes, we obtain, in the stationary case, an integral equation for n_r. This equation may be solved approximately by a variational method in which the maximum value of a characteristic functional gives directly the fraction, Δ, of excitation energy returned to the electrons by de-excitation encounters. Calculations of n_r and Δ have been carried out for the case of Doppler broadened radiation.

[1] T. Holstein, Phys. Rev. **72**, 1212 (1947).

E13. Types of Sparking in High Vacuum Diodes. W. E. RAMSEY AND W. E. DANFORTH, *Bartol Research Foundation.*—Studies of sparking phenomena in high vacuum diodes with barium-strontium oxide cathodes show a multiplicity of phenomena which has led us to speak of four types of sparking. The classification is based upon the nature of the triggering mechanism; the appearance of the sparks bear no relation to the type. It is found that disruptive breakdown occurs when any one of the following conditions obtain: (a) The current density from any point on the cathode exceeds a certain critical value. (b) The field at any point of the cathode exceeds a certain critical value. (c) The electrons striking the anode exceed a critical energy. (d) Points on the anode reach a critical temperature. Types (a) and (b) are referred to as "cathode initiated sparking." Highly active cathodes will exhibit type (a) in the space-charge-limited state, whereas type (b) will predominate with a poor emitter, operating in the emission-limited state with high anode potentials. Types (c) and (d) are anode initiated with the latter being the most frequent cause of breakdown under operation with long pulses (10 microseconds and greater). The experimental basis for this classification will be described. The work was done under OSRD and is now in the province of Bureau of Ships.

E14. Thermal Emittance of Various Materials Used as Anodes in Radio Receiving Tubes. A. D. POWER, *Radio Corporation of America.*—Thermal emittance measurements have been made at several temperatures up to 400°C on various old and new materials used as anodes in radio receiving tubes. The values obtained at 200°C range from 0.12 for uncoated nickel, to 0.98 for a new nickel-coated steel base with a mixed carbon and graphite coating. Basic equations are presented, followed by a brief description of the apparatus and procedure together with results obtained and a discussion of their accuracy.

E15. Ballistic Treatment of the Traveling Wave Amplifier.* D. L. BENEDICT, *Harvard University.*—A first-order theory for the traveling wave interaction of beams and slow electromagnetic waves to attain significant amplification in the microwave region has been developed. Newton's laws are applied to describe the balance of energy in the exchange between wave and beam and the resulting growth of stored electromagnetic energy in a reference system moving with the velocity of the wave. The results are translated back to the stationary system showing the dependence of gain on electron and wave velocity, beam current, and other measurable quantities. Two restrictions are imposed; namely, (a) $(v_e-v_p)\tau 2\pi/\lambda_g \ll 1$, (b) the energy extracted from the beam shall not be large compared with $mv_p(v_e-v_p)$. The manner in which these restrictions may be removed in application of the theory will be indicated

* Work supported by Office of Naval Research.

THURSDAY AFTERNOON AT 2:15

Horace Mann Auditorium

(FRANCIS BITTER presiding)

Solid State: Magnetism and Nuclear Resonance

F1. Measurement of Longitudinal Magnetostriction with Automatic Recording. E. A. NESBITT AND H. J. WILLIAMS, *Bell Telephone Laboratories.*—A new method of measuring magnetostriction is described which permits one to record automatically the change in length of a magnetic specimen, resulting from a change in magnetic field strength. One portion of a ring specimen is rigidly clamped and the diametrically opposite point is connected to a cylindrical coil (*L*-coil) which is suspended in a radial magnetic field so that the axial motion of the coil produces a change in its flux linkages. The specimen is toroidally wound (*H*-coil), and the terminals of the *H*-coil and *L*-coil are connected to a Cioffi recording fluxmeter.[1] A change of current through the *H*-coil actuates the mechanism and change in length is plotted automatically against magnetizing field on a $7\frac{1}{2}''\times 10''$ sheet. Use of this instrument is illustrated for a "soft" magnetic material, vanadium Permendur (49 percent iron, 49 percent cobalt, 2 percent vanadium) having a magnetostriction of 51×10^{-6} for an *H* of 830 oersteds, and for a "hard" magnetic material, Alnico V, having a magnetostriction of 30×10^{-6} for an *H* of 1600 oersteds. This and other materials for permanent

magnets are found to have high magnetostriction in accordance with theory.

[1] Phys. Rev. **67**, 200 (1945).

F2. Energy Calculations for Domains. W. SHOCKLEY, *Bell Telephone Laboratories.*—The origin, shape, and size of the tree patterns described by Williams and Bozorth can be understood in terms of the energies involved and the orientation of the surface. The underlying domain structure which is polarized in the (0 ± 10) easy direction produces a surface charge $\pm I\sin\theta$ where the normal to the surface is $(0, \sin\theta, \cos\theta)$, leading to a magnetostatic energy of $1.70\ I^2\sin^2\theta W/(1+\mu^*)$ per unit area, where W is the width of the domain structure and μ^* is the permeability of the domains in fields perpendicular to the (010) direction. Domains of closure which eliminate all the magnetostatic energy can be constructed by using (±100) domains joining the (0 ± 10) domains across walls whose normals are parallel to $(\pm\sin\theta, \sin\theta, \cos\theta)$. For $\theta>4°$ and $W>0.01$ cm the wall energy required for closure is less than the magnetostatic energy. Complete elimination of magnetostatic energy does not occur because a more stable state can be produced by leaving some free poles and eliminating some wall energy. At smaller slopes this results in the tree patterns. Numerical calculations, including the effect of magnetostrictive energy, show semiquantitative agreement with all observed features, including predictions of the direction of spin precision in domain walls.

F3. New Magnetic Powder Patterns and their Interpretation. H. J. WILLIAMS AND R. M. BOZORTH, *Bell Telephone Laboratories.*—New types of powder patterns, and explanations of types previously reported,[1] have been obtained by deposition of colloidal magnetite on electrolytically polished surfaces of single crystals of iron containing 3.8 percent silicon. A specimen, having its long dimension almost parallel to a (110) direction, has domains of sheet or slab form set transverse to the long dimension, as postulated by Neel.[2] Lack of exact parallelism of the surface with a (001) plane causes the formation of domains of closure having a form suitable for carrying transverse flux. A surface parallel to a $(0\bar{1}1)$ plane has a complicated structure, the main features of which are understood. When a field is applied normally to a specimen cut almost parallel to a (100) plane and having a "dagger-blade" pattern,[3] some of the lines are intensified and some obliterated; from this the variation of magnetization across the Bloch wall can be determined.

[1] H. J. Williams, Phys. Rev. **72**, 529 (1947).
[2] Neel, J. de phys. et rad. **5**, 241 (1944).
[3] H. J. Williams, Phys. Rev. **70**, 106 (1946).

F4. Anomalous Magnetic Susceptibilities of Zinc Single Crystals at 4.2°K. S. G. SYDORIAK, *Yale University.**—The de Haas-van Alphen effect was discovered in zinc by J. A. Marcus and was studied by him at temperatures down to 14°K by measuring the body force on a single crystal. Although the magnetic susceptibility perpendicular to the hexagonal axis, $\chi_\perp$, was -0.150×10^{-6} for all fields and for all temperatures from 100°K to 14°K, $\chi_\parallel$ alternated with field at 14°K. Using a torsion method to measure $(\chi_\parallel-\chi_\perp)$ and a cryostat suitable for work at liquid helium temperatures, it is found that at 4.2°K the effect is much more pronounced than at 14°K. In the range 1.3 to 3 kilogauss, $(\chi_\parallel-\chi_\perp)$ changed sign 18 times. At fields >2 kilogauss the peak-to-peak variation is 0.340×10^{-6}, so, if we can assume $\chi_\perp=-0.150\times10^{-6}$, $\chi_\parallel$ actually swings between diamagnetic and paramagnetic values. Spacing of the peaks is such that $1/H$ of adjacent peaks differs by 0.046 ± 0.001 per kilogauss, in qualitative agreement with Blackman's theory. Above 3 kilogauss, however, the spacing is greater. At constant field the effect of ϕ, the angle between field and hexagonal axis is striking. Between $-90°$ and 0° there were 12 minima and 11 maxima in $(\chi_\parallel-\chi_\perp)$. The amplitude of the swings is greatest at $\phi=0$ and symmetrical about $\phi=0°$. At room temperature $(\chi_\parallel-\chi_\perp)$ is -0.048×10^{-6}.

* Assisted by the Office of Naval Research.

F5. Ferromagnetic Resonance Absorption in a Single Fe Crystal.* ARTHUR F. KIP AND ROBERT D. ARNOLD, *Massachusetts Institute of Technology.*—Ferromagnetic resonance in a single iron crystal† at microwave frequencies has been observed by methods similar to those of Griffiths.[1] For a given frequency, the value of applied magnetic field, H_s, necessary for maximum absorption has been measured as a function of the angle θ between H_s and the crystal axis. For $\nu=23{,}670$ mc/sec., H_s for resonance is 2480 gauss in the (100) direction and 3280 gauss in the (110) direction. Values at 9250 mc/sec. are 210 gauss and 930 gauss, respectively. Results are consistent with Kittel's theory.[2] Results at the higher frequency (requiring relatively large H_s) are consistent with the assumption that M_s, the magnetic moment/unit volume, aligns with H_s. Results at the lower H_s required at 9250 mc/sec. are consistent with the known fact that at the values of H_s used M does not always align with H_s. A consequence of this is that for θ near 45° a second resonance is found at a lower value of H_s.

* This work has been supported in part by the Air Materiel Command, the Signal Corps, and the O.N.R.
† Kindly loaned by Bell Telephone Laboratories.
[1] J. H. E. Griffiths, Nature **158**, 670 (1946).
[2] Charles Kittel, scheduled to appear in Phys. Rev. **73**, 155 (1948).

F6. Paramagnetic Resonance Absorption in Copper Sulfate.* ROBERT D. ARNOLD AND ARTHUR F. KIP, *Massachusetts Institute of Technology.*—The method for studying paramagnetic resonances in a magnetic field at microwave frequencies used by Zavoisky,[1] Cummerow and Halliday,[2] and others has been applied to a single crystal and to a powder of $CuSO_4\cdot H_2O$. The frequency used was 9047 mc/sec. The magnetic field necessary for maximum absorption in the single crystal was studied as a function of the angle between the magnetic axis of the crystal and the direction of the magnetic field. Anisotropy in the crystal was found to cause a variation in the magnetic field for resonance of from 3020 gauss for the magnetic axis parallel to the field to 2800 gauss for the magnetic axis perpendicular to the magnetic field. Results in the powder are in at least qualitative agreement with single-crystal results.

Theoretical considerations referring to these results are given in the preceding paper by Van Vleck.

* This work has been supported in part by the Air Materiel Command, the Signal Corps, and the O.N.R.
[1] E. Zavoisky, J. Phys. U.S.S.R. **10**, 170 (1946).
[2] R. L. Cummerow and D. Halliday, Phys. Rev. **70**, 433 (1946).

F7. Ferromagnetic Resonance Absorption at Microwave Frequencies. W. A. YAGER, *Bell Telephone Laboratories.*—After having observed[1] the sharp resonance absorption at a wave-length of 1.25 cm in annealed Supermalloy, further experiments have been carried out in several materials subjected to various superposed field strengths. New measurements on an annealed sample of Supermalloy over the range from 15 to 7500 oersteds indicate that the apparent r-f permeability μ_R, for 1.25-cm waves, has a minimum value of around 0.09 at about 200 oersteds, and at lower fields increases rapidly to unity as the applied magnetic field decreases toward zero. This behavior is compared with theory. In the unannealed condition, after severe cold rolling, the resonance maximum is broader than in the annealed state but its position and, therefore, the "g" value remain unchanged. Measurements on a hydrogen-treated sample of pure iron and an annealed sample of nickel are in general agreement with the results reported in the original paper of Griffiths.[2]

[1] W. A. Yager and R. M. Bozorth, Phys. Rev. **72**, 80 (1947).
[2] J. H. E. Griffiths, Nature **158**, 670 (1946).

F8. Effects of Nuclear Electric Quadrupole Moments in Nuclear Paramagnetic Resonance Absorption. R. V. POUND, *Harvard University.*—In liquids $\partial^2 V/\partial z^2$ fluctuates very rapidly as a consequence of thermal agitation and averages nearly to zero in one r-f period. Thus a nuclear electric quadrupole moment affects the absorption line due to the nuclear magnetic moment only through a shortening of the "spin-lattice" relaxation time, T_1. This effect has been found to be large for aqueous solutions of Br^{79} and Br^{81}, providing identification of the two lines through their different widths. In crystals having lower than cubic symmetry the magnetic moment lines of nuclei possessing quadrupole moments should be split by the interaction with $\partial^2 V/\partial z^2$, z being along the field direction. The Li^7 lines in powdered Li_2CO_3 and $Li_2SO_4 \cdot H_2O$ have been found to spread over 80 and 50 kc/sec. and to have shapes in agreement with a quadrupole interaction. In single crystals of $Li_2SO_4 \cdot H_2O$, the Li^7 line has been found to break up into three components for certain orientations of the crystal in the magnetic field. Experiments are under way to determine the dependence of the splitting on orientation to see if it is in agreement with estimates, based on the crystal structure, of $\partial^2 V/\partial z^2$, to which the H_2O molecule may be a large contributant.

F9. Fine Structure of the Proton Paramagnetic Resonance Line in Crystalline Hydrates. G. E. PAKE, *Harvard University.*—Fine structure has been observed in the nuclear resonance absorption line for protons in crystalline hydrates. The stability of a permanent magnet, which provided the field of 6820 gauss, facilitated line shape studies. Measurements on a single crystal of $CaSO_4 \cdot 2H_2O$ reveal four component lines with pattern width varying from zero to 22 gauss, depending upon the magnetic field direction in the crystal. The number of component lines and the dependence of their spacing on field direction are calculated by treating the magnetic dipole-dipole interaction as a perturbation of the two-proton system in the water molecule; the more distant proton moments, neglected in this calculation, provide finite width for the component lines. Variation of the splitting with field direction determines the orientation in the lattice of the line connecting protons of the water molecule. The length of this line in $CaSO_4 \cdot 2H_2O$ is measured by the splitting to be 1.58A; for an assumed H—O—H bond angle of 108°, the O—H distance is 0.98A. The isotropically oriented microcrystals of powdered hydrates lead to a characteristic fine structure which determines the proton-proton distance somewhat less accurately.

F10. Orientation of Domains in Polycrystalline $BaTiO_3$. G. C. DANIELSON, *Bell Telephone Laboratories.*—The orientation of domains in $BaTiO_3$ polycrystalline ceramic disks has been determined from back reflection x-ray diffraction photographs as well as from their piezoelectric effects.[1–3] The observed changes in the relative intensity of the (510) and (015) planes, using copper radiation, and the (311) and (113) planes, using chromium radiation, upon application of an electric field can be interpreted in terms of orientation of the ferroelectric domains. A method of quantitatively measuring the angular distribution of domains is indicated. Just above the Curie temperature the application of an electric field changes the symmetry of many $BaTiO_3$ crystals as shown by an increase in the number of non-cubic crystals.

[1] S. Roberts, Phys. Rev. **71**, 890 (1947).
[2] W. P. Mason, Phys. Rev. **72**, 869 (1947).
[3] W. L. Cherry and R. Adler, Phys. Rev. **72**, 981 (1947).

F11. The Existence of Relations Among the Thermomagnetic and Galvanomagnetic Coefficients.* H. B. CALLEN, *Massachusetts Institute of Technology.*—The application of Onsager's reciprocal relations** to the thermomagnetic and galvanomagnetic effects in isotropic systems allows one to express the coefficients of all the effects in terms of six independent "kinetic coefficients." There are, thus, two independent relations among the eight commonly defined*** coefficients in a magnetic field. One of these relations, connecting the Ettinghausen and Nernst coefficients and the isothermal heat conductivity, has been previously obtained by Bridgman, but there has hitherto been some doubt and speculation as to the existence of relations other than this. The second relation is a rather complicated one, but may be shown to degenerate in weak magnetic fields into the equalities between the adiabatic and isothermal values of the electric and heat conductivities.

* This work was supported by O.N.R.
** L. Onsager, Phys. Rev. **37**, 405 (1931); **38**, 2265 (1931).
*** A. Sommerfeld and N. H. Frank, Rev. Mod. Phys. **3**, 1 (1931).

THURSDAY AFTERNOON AT 2:15

Pupin 428

(E. F. KINGSBURY presiding)

Optics

G1. Antenna Current Distributions.[1] RICHARD C. RAYMOND AND WAYNE WEBB, *Pennsylvania State College.*—An apparatus has been built and used to measure the current amplitude distributions on some types of high frequency antennas. Comparison of the measured distributions with several assumed distributions shows that none fit very precisely. Calculation of radiation resistances from the current distributions by the Poynting vector method gives fair agreement with measured resistances as determined by the standing-wave method. The differences between the measured and commonly assumed distributions are such that their effects on the radiation resistance are relatively small.

[1] This work was supported in part by the Army Air Forces.

G2. Nuclear and Molecular Magnetic Moments in Microwave Zeeman Spectra.* C. K. JEN, *Harvard University.*—The Zeeman effect of a number of microwave spectral lines has been studied by applying a magnetic field in a resonant cavity which acts as the absorption cell. In a detailed investigation of ordinary ammonia gas, the doublet separation in a weak magnetic field was found to be approximately 0.72 mc per 1000 gauss. The Zeeman separation proves to be very nearly independent of the quantum numbers for various spectral lines, in agreement with the results of Coles and Good.[1] Almost the same constant separation applies to the satellites due to nuclear quadrupole moments. The observed effects can be explained theoretically only when we assume that the g-factor due to N^{14} nuclear spin and that due to molecular rotation are of the same order of magnitude, and that for a weak field the two g-factors combine through the spin-rotation coupling. The analysis yields a g-factor 0.48 ± 0.03 for the molecular moment, when one uses the known value of 0.403 for the N^{14} nuclear moment, both expressed in nuclear magnetons. Thus, measurements of the Zeeman effect for microwave spectra should provide a new source of information about the nuclear and molecular magnetic moments and the way they are coupled.

* The research presented in this abstract was carried out under contract with the Office of Naval Research and the Signal Corps.
[1] D. K. Coles and W. E. Good, Phys. Rev. **70**, 979 (1946).

G3. Pure Rotational Spectrum of ICl. C. H. TOWNES*, B. D. WRIGHT,** AND F. R. MERRITT, *Bell Telephone Laboratories.*—About thirty lines due to the $J=3->4$ rotational transition of ICl have been found at wave-lengths near 1.1 cm. From these lines the nuclear quadrupole coupling, $eqQ\equiv eQ(\partial^2V/\partial z^2)$, may be determined for I as minus 2930 mc, and for Cl^{35} as minus 82.5 mc. The iodine coupling is so large that effects[1] of the order $(eqQ)^2/B$ must be taken into account in order to fit the experimental results adequately. A line due to molecules in the first excited vibration state was detected so that the rotational constants B_e and α_e can be determined as 0.114164 cm^{-1} and 0.000536 cm^{-1}, respectively, for ICl^{35}. These are in agreement with previous, less accurate determinations.[2] The frequency interval between ICl^{37} and ICl^{35} lines gives a mass difference between Cl^{37} and Cl^{35} about one part in 2000 less than mass-spectroscopic measurements.[3]

* Now at Columbia University.
** Now at University of Chicago.
[1] Bardeen and Townes, Phys. Rev. to be published.
[2] Curtis and Patkowski, Phil. Trans. Roy. Soc. **232**, 395 (1934).
[3] Mattauch, *Nuclear Physics Tables* (Interscience Publishers, Inc., 1946), p. 130.

G4. Stark Effect in High Frequency Fields. F. R. MERRITT AND C. H. TOWNES,* *Bell Telephone Laboratories.*—Stark effect on molecular lines falling in the microwave region has been obtained by a number of workers. Because of the relatively long time required for radiation absorption to take place at microwave frequencies, the Stark field may be varied appreciably during one absorption process. A solution of the time-dependent wave equation can be obtained by perturbation methods which is good for any frequency of variation of the Stark field small compared to other molecular frequencies. At low frequencies this solution reduces to the normal static-field solution. At frequencies of the order of the line width 1 megacycle, the Stark components do not change frequency synchronously with the Stark field, but new lines appear in the absorption spectrum separated by integral multiples of the frequency of the applied field. At still higher frequencies the spectrum is again reduced to the normal number of Stark components, but their frequencies represent an average of the Stark field. These effects have been observed experimentally with the $J=1->2$ line of OCS. Relative intensities of lines under different conditions have been calculated and agree well with experimental results. A similar behavior should be produced by other time-dependent perturbations.

* Now at Columbia University.

G5. Microwave Absorption Spectrum of COSe.* M. W. P. STRANDBERG AND T. WENTINK, JR., *Massachusetts Institute of Technology.*—The $J=2$ to 3 transition in the pure rotation spectrum of COSe, which is a linear molecule, was investigated using a Stark modulation microwave spectroscope.[1] The spectrum which lies between 23,500 and 24,500 Mc/sec. contains lines due to all the known stable isotopes of selenium in conjunction with the C^{12} and O^{16} isotopes. No quadrupole effects were observed. Rough measurements of intensity ratios are in agreement with the

reported abundances. Weaker lines were observed for $C^{13}O^{16}Se^{8}$ and $C^{13}O^{16}Se^{78}$ and for excited vibration states of the $C^{12}O^{16}Se$ molecule with several selenium isotopes. The symmetrical stretching $v_1=1$ and the bending vibration $v_2=1$ were excited in sufficient amounts to be observed. From the intensity compared to the ground state lines the fundamental infra-red vibration frequency ω_2 has been estimated to be 440 cm^{-1}. Further work is in progress to obtain accurate mass ratios and interatomic distances.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

[1] R. H. Hughes and E. B. Wilson, Jr., Phys. Rev. **71**, 562 (1947).

G6. Stark Effect in the COSe Molecule.* T. WENTINK, Jr., M. W. P. STRANDBERG, AND R. HILLGER, *Massachusetts Institute of Technology.*—The Stark splitting has been measured for many of the lines in the COSe spectrum near 24,000 Mc/sec. A square-wave Stark voltage was used with the Stark electrode essentially grounded for half the cycle so that the Stark components and the undeviated line are both sharp. Field strengths of 7.5 kv/cm are obtainable. The Stark field is parallel to the microwave electric field and only the π components of the spectrum are observed. For the $J=2$ to 3 transition in COSe, components are observed for $m=0$, ±1, and ±2 which are well resolved from the undeviated line. In the ground vibration state they show a quadratic Stark effect, which corresponds to a dipole moment of 0.752 ± 0.007 Debye units. Values for the several selenium isotopes are the same within experimental error. The quadratic Stark splitting has also been measured for molecules in the $v_1=1$ stretching vibration mode. The dipole moment measured for this state is 0.728 ± 0.007 Debye units. The lines for the excited bending vibration show a linear Stark effect except for Stark splittings that are small compared to the l-type doubling.

* This work has been supported in part by the Signal Corps, the Air Materiel Command, and O.N.R.

G7. Minimum Detectable Absorption in Microwave Spectroscopy and an Analysis of the Stark Modulation Method. W. D. HERSHBERGER, *Radio Corporation of America.*—It is shown that the minimum detectable absorption coefficient for an isolated spectral line, as measured in a matched wave guide of optimum length, is $[(4kTN\Delta f)/(Po/e)]\alpha_c$, where N is the noise factor and Δf the band width of the receiver, α_c is the attenuation constant for the wave guide, and Po/e is the average microwave power available at the receiver. The equivalence between cavity and wave guide methods is developed. The Stark modulation method of Hughes and Wilson is analyzed, assuming a quadratic Stark effect, and expressions are developed for the modulation factor of a microwave at twice and four times the frequency of the Stark field. For a matched guide the modulation factor is $\alpha_c l/4$. Also the shift in line position is calculated, and finally, the directions in which improvement in sensitivity may be expected are indicated.

G8. Theory of the Width of Microwave Lines in Cupric Salts. J. H. VAN VLECK, *Harvard University.*—In a magnetic field of the order 10^3 gauss, cupric salts have a resonance absorption in the microwave region caused by the magnetic dipole moment of the electron spin. Since a crystalline field cannot split the twofold degeneracy of the ground level, the absorption lines for a single crystal are broadened only by dipolar coupling. The phenomenon of "exchange narrowing"[1] makes this broadening less than one would calculate from the mean square under the Gaussian hypothesis. As the result of the action of the crystalline field, the g-factor is anisotropic. Hence, the position of the lines in single crystals depends on the orientation of the principal axes relative to the magnetic field. This anisotropy broadens the lines for a powder even without the dipolar effect. A calculation is made of the resulting line structure on the basis of the model of the crystalline field for $CuSO_4\cdot5H_2O$ developed by Krishnan and Mookherji[2] and by Polder.[3] Comparison with experiment is made in the following paper by Arnold and Kip.

[1] C. J. Gorter and J. H. Van Vleck, Phys. Rev. **72**, 1128 (1947).
[2] K. S. Krishnan and A. Mookherji, Phys. Rev. **54**, 533, 841 (1938).
[3] D. Polder, Physica **9**, 709 (1942).

G9. Anomalies in the Infra-Red Spectra of Phosphine and Arsine. VIRGINIA M. MCCONAGHIE AND HARALD H. NIELSEN, *Ohio State University.*—The infra-red spectrum of phosphine has been measured by Fung and Barker[1] who interpreted it on the basis that the molecule is an accidentally spherical rotator. The spacing between rotation lines in the fundamental bands ω_1 and ω_3, however, leads to rather different values of the moment of inertia of the molecule. It is found in measurements made here that much the same condition exists for the AsH_3 and AsD_3 molecules. It may be demonstrated that the spacing between rotation lines in the two fundamental bands ω_3 and ω_4, which overlap each other in the spectra of all these molecules, may be expected to be anomalous. The frequency ω_3, which is along the z axis (symmetry axis) of the molecule and the twofold degenerate frequency, ω_4, which is in the xy plane of the molecule, are nearly alike. This resonance gives rise to a first-order Coriolis interaction between a nearly isotropic three-dimensional oscillator and an accidentally spherical rotator. In the P and R branches of the frequencies ω_3 and ω_4 ($\omega_3<\omega_4$) a value for the rotational spacing between rotation lines $\Delta\nu=(1+\zeta')(h/4\pi^2Ic)$ is predicted; in the R and P branches of these same bands a rotational line spacing of $\Delta\nu=(1-\zeta')(h/4\pi^2Ic)$ is expected as J assumes large values. ζ' may be regarded as the Coriolis coupling coefficient.

[1] Lai Wing Fung and E. F. Barker, Phys. Rev. **45**, 238 (1934).

G10. Interaction of Nuclear Quadrupole Moments with Molecular Rotation in Asymmetric Rotor Molecules. J. K. BRAGG, *Harvard University.*—A theoretical treatment is given of the splitting of the rotational levels of an asymmetric top molecule due to interaction of electric quadrupole moments of one or two nuclei with the electric field of the molecule. The matrix elements of the coupling operator $3(\mathbf{I}\cdot\mathbf{J})^2\cdot\frac{3}{2}\mathbf{I}\cdot\mathbf{J}-\mathbf{I}^2\mathbf{J}^2$ are the same as for linear molecules and symmetric tops, but the parameter $\langle 3\cos^2\theta-1\rangle_{kl}$ depends on the transformation which diagonalizes the energy of the asymmetric top in question, and involves two constants of the molecule for a given vibrational and electronic state,

$\partial^2V/\partial z^2$ and $\partial^2V/\partial x^2-\partial^2V/\partial y^2$, where x, y, z refer to the directions of the principal axes and V is the electrostatic potential at the nucleus in question. The possibility of use of these facts in identification of asymmetric rotor spectra is mentioned, and experimental work in progress on two molecules, CHF_2Cl and CH_2Cl_2, is described.

G11. Absorption by N_2 and O_2 of Solar Wave-Lengths in the Extreme Ultraviolet. K. C. CLARK, *Harvard University.*—The presence of ionized layers in the upper atmosphere is known to depend in part on the incident solar radiation, which undoubtedly contains prominent emission lines of H and He at wave-lengths sufficiently short to ionize the atmospheric gases. Absorption coefficients of N_2 and O_2 were measured with a vacuum spectrograph with an electrodeless discharge to produce with constant intensity the H Lyman series through the seventh member (λ926) and the principal line λ584 of the HeI series. From the absorption coefficients measured for H Lyman X, 3···7 and HeI λ584, the height of maximum absorption by the atmosphere is computed for each wave-length with standard estimates of the composition and temperature. The *F* layer may plausibly be assigned to ionization of H_2 and O by HeI λ584. Because of their strong absorption by N_2, far above the dissociation height of O_2, the lines of H and HeI measured cannot ionize atmospheric O_2. Similarly, none of the lines measured can penetrate to the height of the *D* layer. The *E* layer may still be attributed to possible ionization of O_2 by higher members of the Lyman series or by continuous blackbody solar radiation in the range λλ1010–910.

G12. Experimental Check on Intensity Distribution in Small-Angle X-Ray Scattering. JOHN TURKEVICH AND HARRY H. HUBBELL, JR.,* *Princeton University.*—The Guinier formula for the intensity of x-rays scattered at small angles by finely divided materials has been checked experimentally in several respects. With a sample of carbon black, seven crystal-monochromated wave-lengths gave scattered intensity *versus* angle curves which superposed within experimental error over a 10,000 to 1 intensity range when the angles were divided by the appropriate wave-lengths. The wave-lengths used ranged from 0.71 to 2.28A. Three filtered $K\alpha$ wave-lengths gave similar results on this sample and also on three gold colloids and several other samples. A gold colloid prepared by precipitation with sodium citrate from gold chloride solution gave a scattering curve agreeing with that predicted over a fifteenfold intensity range for three wave-lengths. Electron microscope pictures show this colloid consists of spherical particles of 200 ± 24A diameter, with about 57 percent of the particles falling in this range. The scattered intensity curve shows unmistakably the first secondary maximum in intensity predicted by the theory and in nearly the right position. Intensities were measured by a Geiger counter whose linearity was repeatedly checked. Photographs also show the secondary maximum shifting with wave-length as predicted.

* Now at Middlebury College.

G13. The Effect of Apparatus Geometry on Small-Angle X-Ray Scattering Curves. HARRY H. HUBBELL, JR., *Princeton University.*—It was calculated that the frequently used Gaussian-error type approximation to the intensity as a function of angle for x-rays scattered by finely divided materials was not valid for intensities less than one-tenth that scattered at zero angle. Calculations showed that the secondary maxima and minima predicted by Guinier's[1] exact scattering theory for homogeneous spherical particles will be smeared out by the use of slits instead of pinholes to define the x-ray beam. The first secondary maximum will move toward smaller angles as the slits are made longer. Increasing the length of the slit rapidly fills the minimum of the intensity curve, but raises the intensity of the secondary maximum much less. Methods suggested by other workers for correcting scattering curves observed with slit geometry to corresponding pinhole curves destroy any secondary peaks which might appear. These peaks have been observed (see previous paper). The effect of a distribution in particle sizes was shown to be a further smearing out of the secondary maximum until as narrow a spread as one having a mean deviation of 12 percent in particle diameter gives a scattering curve without any secondary peak.

[1] A. Guinier, Ann. de physique **12**, 161 (1939).

G14. A High Temperature X-Ray Diffraction Camera.* JAMES W. EDWARDS, RUDOLPH SPEISER, AND HERRICK L. JOHNSTON, *The Ohio State University.*—In this Laboratory, we have developed an x-ray powder diffraction camera that is designed for use up to 3000°K. The sample in form of a wire, compacted rod, or contained (wherever suitable) in a thin-walled quartz or ceramic tube is heated indirectly by conduction and radiation in a thin-walled graphite, tantalum, molybdenum, or tungsten furnace. The furnace is heated by high frequency (0.5 megacycle) eddy currents induced by a small induction coil. The cylindrically shaped furnace and the sample are held coaxially in the induction coil and slowly revolved. The specimen temperature is maintained constant to ±0.2 percent by an especially designed temperature regulator. A copper water-cooled jacket, with slots fitted with metal foil to filter the diffracted x-radiation, completely surrounds the furnace and is used to protect the x-ray film from the heat and light. The Straumanis film arrangement is used. The temperature of the furnace is measured with a disappearing filament optical pyrometer. The entire camera is evacuated and operated at pressures less than 1×10^{-4} mm Hg. X-ray diffraction patterns of molybdenum at 2000°K have been made. Copper $K-\alpha$ radiation has been used and exposure times of 2 hours. Very satisfactory patterns of molybdenum were obtained.

* Supported by the Office of Naval Research.

G15. On the Diffraction of X-Rays from Coarse Powders. ZIGMOND W. WILCHINSKY, *Standard Oil Company of New Jersey, Louisiana Division.*—In developing the integrated intensity equation for diffraction of x-rays from coarse powders, it is necessary to consider the contribution of

diffracted energy from each particle. For any particle below the surface of the sample, the incident and diffracted rays are of course attenuated. In a previous development[1] the required absorption factor was computed in the same manner as for a fine powder, whereas in the present treatment the absorption factor is obtained by considering the statistical distribution of coarse particles. The predictions of these two theories differ conspicuously for the case of a coarse powder consisting of a single crystalline phase. According to the older theory, the integrated intensity should not be affected by particle size; however, the proposed theory predicts that under certain conditions the integrated intensity could be considerably lower than for an ideal fine powder. Experimental results indicate that the integrated intensity decreases with increasing particle size and decreases with decreasing degree of compaction of the powder, in accord with the new theory.

[1] G. W. Brindley, Phil. Mag. 36, 347 (1945).

THURSDAY AFTERNOON AT 2:30

McMillin Theatre

(J. R. OPPENHEIMER presiding)

Cosmic Rays

H1. Test of the Hypothesis that the Sea-Level Cosmic-Ray Meson Disintegrates into a Photon and an Electron.* R. D. SARD AND E. J. ALTHAUS, *Washington University.*—The hypothesis has been tested by searching for delayed coincidences between the 50-Mev photon, detected by its materialization in a Pb sheet and the arrival of the meson that gets stopped. From top down: Geiger-Mueller tubes, A; 12.5-cm Pb filter; G-M tubes, B; 21.6 g/cm² brass absorber; anti-coincidence G-M tubes, C; 9.74 g/cm² Pb photon converter (calculated chance of at least one electron emerging, 50 to 60 percent); G-M tubes, D; G-M tubes, E. The circuit[1] records simultaneous and delayed coincidences ($AB:DE$) between coincidences of D and E and of A and B For detecting the photon, an anti-coincidence circuit permits registration only when C is not triggered within 10 μsec. Without C and the Pb sheet, ($AB:DE$) delayed 1.16 to 7.93 μsec. (due to decay electrons from brass) occur at 0.42 ± 0.07/hr. With C and the Pb sheet, ($AB-C:DE$) delayed 1.16 to 7.93 μsec. (decay photons from brass) should occur at about 0.24/hr. if the hypothesis is correct. There have been only 4 in 314 hrs., and these can be accounted for by the measured inefficiency of C.

* Work supported in part by the U. S. Navy.
[1] We are indebted to B. Rossi, M. Sands, and M. H. Hubbard of M.I.T. for provision of the coincidence circuit. It was designed by Sands (B. Rossi, M. Sands, and R. D. Sard, Phys. Rev. 72, 120 (1947)).

H2. The Decay of Slow Mesons.* G. E. VALLEY, *Massachusetts Institute of Technology.*—The mean life for decay of slow positive and negative mesons has been examined for mesons stopped in beryllium. Within the experimental error, the mean lives of mesons of both signs is equal to the accepted value of about 2.2 μsec. It is found that approximately equal numbers of mesons of each sign decay in beryllium. There is no evidence that more than one charged particle is emitted during the decay of either a positive or a negative meson in beryllium. The experiment is now being repeated to find out the behavior of mesons stopped in magnesium.

* The research described in this letter was supported partially by the Office of Naval Research.

H3. The Production of Mesotrons in Cosmic-Ray Stars in the Stratosphere.* J. J. LORD AND MARCEL SCHEIN, *University of Chicago.*—Two Ilford, type C2 plates sent along with a free-balloon experiment in the stratosphere were exposed to cosmic radiation at an altitude greater than 60,000 feet for a period of eight hours. In the two square centimeters of the plate examined so far, the rate of star production corresponded to approximately 6000 stars of more than 4 long-range particles per cubic centimeter of emulsion per day. In some of the stars, nuclei heavier than α-particles were emitted which then disintegrated at the end of their range into two particles ("hammer track"). One of the stars consisted of ten well separated particles emitted from a common center. Two of the tracks in this star were identified as protons by their total number of grains *versus* range.[1] Two very long-range tracks (917 and 1512 microns), one of which originated in the center of a star and both stopping in the emulsion, were identified as mesotrons. Since, in these events of mesotron production, the total energy in the stars appears to be only a few hundred Mev, it does not seem to be impossible that mesotrons can be created artificially by the recently developed high energy machines.

* This research was supported in part by the U. S. Navy.
[1] Lattes, Occhialini, and Powell, Nature 160, 453 (1947).

H4. On the Interpretation of Data on Large Air Showers.* JOHN M. BLATT, *Massachusetts Institute of Technology.*—Two ionization chambers of area A, a distance $2a$ apart, record a count only if more than N particles traverse *each* chamber. Assuming all showers to hit vertically, let $S(N_0)$ be the number of showers per unit area per second in which *more* than N_0 particles cross the plane of observation. We assume the *same lateral structure function $f(r)$ for all showers*, i.e., the particle density a distance r from the shower axis is $p(r)=N_0f(r)$. If we neglect the finite size of the chambers, the counting rate $W(N,a)$ is an integral involving $S[N/Af(r)]$. The integral equation can be inverted, giving $S[N/Af(r)]$ as an integral involving $\partial^2W/\partial a^2$. The implications of this solution will be discussed. We then

assume $S(N_0)$ proportional to $N_0^{-\gamma}$, and $f(r)$ = Molière's expression.[1] $W(N, a)$ was computed for $r = 1.65, 1.70, 1.75$. The curves show extremely sharp drops between $a = 0$ and $a = 0.005$ characteristic units (about 1-meter separation). The correction for the finite chamber size was found explicitly. It decreases the drop somewhat but does not eliminate it. The experimental results of Williams will be compared with this theory in the following paper.

* The research described in this abstract was supported partially by the Office of Naval Research.

[1] Heisenberg *et. al.*, *Cosmic Radiation* (Dover Publications, New York, 1946), p. 36.

H5. The Lateral Distribution Function of Cosmic-Ray Air Showers.* ROBERT W. WILLIAMS, *Massachusetts Institute of Technology.*—An arrangement of four ionization chambers with electronic coincidence and photographic recording of pulse height was used to investigate the lateral distribution of particles in large cosmic-ray air showers (Auger showers). The ionization chambers are thin-walled cylinders filled with five atmospheres of argon, purified to permit quantitative electron collection. At an altitude of 10,000 feet the number of two-chamber coincidences caused by showers was measured as a function of the separation between the two chambers, the other two chambers being used to help distinguish showers from nuclear disintegrations. The minimum particle density selected was 300 particles/m², and at all distances the number of coincidences varied approximately as (particle density)$^{-1.7}$. Between 12.2 meters and 0.36 meter the number of coincidences increased by a factor of two, somewhat less than expected from Blatt's calculations using Molière's lateral distribution function for the density of shower particles. This discrepancy, if real, would suggest that the actual distribution function is less concentrated at the core than the Molière function.

* The research described in this abstract was supported partially by the Office of Naval Research.

H6. Ionization Chamber Bursts at High Altitudes.* T. COOR AND G. A. SNOW, *Princeton University.*—A thin-wall, low pressure ionization chamber has been sent aloft by means of balloons to a pressure of 1.5 cm Hg. Sizes of pulses (0.8 to 20×ionization of $Po-\alpha$) were telemetered to ground where they were recorded along with pressure. The frequency of bursts of all sizes increased rapidly up to the highest altitude reached. For bursts $>2Po-\alpha$ the rate *vs.* pressure curve corresponds to an exponential absorption in the atmosphere with a mean free path of 160 g/cm². In the range $0.8-2Po-\alpha$ the increase is much slower with altitude and a leveling off occurs at *ca.* 2 cm Hg. The ionization produced by all bursts $>0.8Po-\alpha$ was computed to be about 12 percent of the total ionization at 1.5 cm Hg. The absolute rate of those events is in fair agreement with the rate of star production found in photographic plates sent with the flights. The most reasonable assumption is that these bursts are stars and that they are closely associated with the primary process.

* Supported by the Office of Naval Research.

H7. The Neutron Density in the Free Atmosphere up to 30,000 Feet Altitude.* LUKE C. L. YUAN AND RUDOLF LADENBURG, *Princeton University.*—By using proportional counters filled with boron trifluoride at 50-cm pressure (containing 96 percent pure boron 10) the neutron density has been measured in the free atmosphere. The counts per minute obtained for neutrons absorbable by cadmium increased from 1.45 ± 0.05 at sea level to 130 ± 1 at 30,000 feet height with a minimum at about 1000 feet of 0.9 ± 0.01. The increase with altitude can be represented by the function $\exp(-ap)$ with $a = 0.09$ if the pressure p is measured in centimeter Hg. This rapid increase is similar to the increase of large bursts with altitude. (See preceding abstract by Coor and Snow.) If we take 1900 barns for the average cross section for the disintegration of boron 10 by slow neutrons, we find that about 0.1 slow neutrons cross 1 cm² per minute at sea level and about 9 slow neutrons cross 1 cm² per minute at 30,000 feet altitude. The results obtained will be compared with previous measurements by Fuenfer, Von Halban, and Korff and by Agnew, Bright, and Froman, also the theoretical implications of the results will be discussed.

* Supported by the Office of Naval Research.

H8. Meson Induced Fission. J. A. WHEELER, *Princeton University.*—Experimental and theoretical evidence suggests that the non-electric interaction between ordinary mesons and nuclei is very weak in comparison to the electric forces. On this assumption it is possible to calculate for a relativistic particle of mass 200 and spin 0 the energy levels in the extended field of the nucleus. In the case of uranium the calculated energy release in the transition from the 2-sec. to the 1-sec. level is 6.7 Mev. The process in which this energy is transferred to the nucleus to cause fission is calculated to compete favorably with radiation, Auger transitions, and pair production. The energy required to produce fission of a nucleus with a meson in the 1-sec. state is calculated to exceed by about 0.6 Mev the normal fission energy. That slow ordinary negative mesons will produce fission appears possible in the case of uranium and reasonably probable in the case of heavier nuclei where the energy available exceeds with greater certainty the threshold for fission.

H9. The Altitude Variation of Large Pulses in Ionization Chambers.* ROBERT I. HULSIZER, *Massachusetts Institute of Technology.*—Ionization pulses occurring in unshielded cylindrical ionization chambers, borne by balloons to altitudes up to 87,000 feet (20 g/cm²), were recorded by means of a radio link to the ground. The chambers were constructed of $\frac{1}{32}$-inch brass, two inches in diameter by $5\frac{1}{2}$ inches long, and were filled with six atmospheres of argon. The number of pulses, corresponding to an energy loss in the chamber of 6.3 Mev, increases by approximately a factor of four between 30,000 feet (306 g/cm²) and 70,000 feet (45 g/cm²).

* The research described in this abstract was supported partially by the Office of Naval Research.

H10. The Absorption in Carbon and Lead of Cosmic-Ray Particles at Very High Altitudes.* MARTIN A. POMERANTZ, *Bartol Research Foundation.*—Curves concerning the

absorption in lead of cosmic-ray particles at very high altitudes have been obtained. These reveal the nature of the variation with altitude of the intensity of the so-called "soft" component (here construed to consist of electrons and slow mesons). A progressive increase in the relative intensity of particles having a range in lead of less than approximately 25 g/cm² occurs at atmospheric depths between 250 mm of Hg and about 80 mm, followed by a rapid decrease apparently to zero at the top of the atmosphere. The absorption coefficient of particles having ranges exceeding the aforementioned value does not vary appreciably with altitude. A comparison of the relative stopping powers of carbon and lead indicates that the absorption in 17 g/cm² of C is equal to that in 8.8 g/cm² of Pb at an atmospheric depth of 250 mm. The Pb-equivalent decreases to 6.1 g/cm² at 100 mm, and thereafter increases with altitude, the value at 50 mm being 13.9 g/cm². A flight with standard apparatus utilizing an out-of-line counter has demonstrated that the effect of showers in the present experiments amounts to less than 5 percent of the measured intensities.

* Supported by Office of Naval Research.

THURSDAY AFTERNOON AT 2:00

Pupin 301

(WALKER BLEAKNEY presiding)

Contributed Papers of the Fluid Dynamics Committee

J1. A Generalization of a Theorem by Larmor in Hydrodynamics. I. OPATOWSKI, *University of Michigan.*—If $S(x_1, x_2, x_3)=$const. is the equation of a surface to which a steady motion of a fluid is constrained, then the streamlines of the flow are determined on that surface by the equation $\int M(q_2dx_1-q_1dx_2)/(\partial S/\partial x_3)=$const., where the q_i's are the contravariant components of the velocity of the fluid, M is any function satisfying the equation $\Sigma_{i=1}^{i=3}\partial(Mq_i)/\partial x_i=0$ and x_3 is intended as eliminated in the integrand of the above formula by means of $S(x_1, x_2, x_3)=$const. If the x_i's are orthogonal cartesian coordinates, then $M=\rho=$the density of the fluid.[1] If the x_i's are general curvilinear coordinates, $M=\rho(a)^{\frac{1}{2}}$, where a is the value of the determinant of the coefficients a_{ij} in the expression for the length of arc: $ds^2=\Sigma_{i,j}a_{ij}dx_idx_j$. The result facilitates the study of streamlines of helical, spiral and general conical flows. In the latter, the streamlines are intersections of skew cones with surfaces of revolution. The result is valid for non-viscous fluids in absence of mass forces. No restrictions on compressibility and rotationality are necessary.

[1] J. Larmor. Rep. Brit. Assoc., 562–563 (1897).

J2. Response Time in Vacuum Gages. S. A. SCHAAF AND R. R. CYR.—A typical system for measuring pressures in a rarefied gas consists of a vacuum gage connected to the gas by a length of tubing, usually with an orifice of diameter smaller than that of the tubing at the end. The interior surface of this system will outgas at a fairly constant rate for a long period of time so that an equilibrium state will be reached with a definite non-constant pressure distribution along the tubing. The response time constant for the system to come to equilibrium and the difference in pressure between gas and gage are functions of the outgassing rate and the geometry of the system. An analysis is made assuming molecular flow and formulas are obtained for the response time and the pressure difference. It is shown that there is an optimum value of the tubing diameter for a given orifice diameter, gage volume and length of tubing. This optimum is rather critical; if the diameter is too small, response time constants of the order of hours may result. Experimental work has been done and the results compared with theory. This work was done under Office of Naval Research Contract.

J3. Selection of Adiabatic Parameters in the Theory of Oscillation of Gas Globes from Underwater Explosions. A. B. ARONS, *Stevens Institute of Technology.*—Three important parameters appearing in the theory of gas globe oscillation[1] are γ, the adiabatic exponent, k, the adiabatic energy constant, and E, the bubble energy per unit mass of the original explosive. These parameters cannot be calculated with sufficient accuracy from *a priori* considerations, but it is shown that if they are selected to fit three independent pieces of experimental evidence, the theory then fits the remaining experimental results and can thus be used to predict bubble pulse properties such as maximum radius, peak pressure, positive impulse, period, etc. over wide ranges of the independent variables. In this theory γ and E are fitted to period data, and k to bubble pulse peak pressure data. The resulting values for TNT are found to be: $\gamma=1.25$; $E=490$ cal/gm; $k=0.0552Z_0^{\gamma-1}$, where Z_0 is the absolute hydrostatic depth in feet.

[1] B. Friedman, "Theory of underwater explosion bubbles." Institute for Mathematics and Mechanics, New York University. Report No. IMM-NYU 166.

J4. Energy Partition in Underwater Explosion Phenomena.* D. R. YENNIE AND A. B. ARONS, *Stevens Institute of Technology.*—A survey is made of existing knowledge with respect to the distribution of energy in underwater

explosions. It is shown that approximately 40 percent of the initial energy is radiated in a series of pressure waves which, from the point of view of energy flux, can be treated as approximately acoustical in the range subject to experimental measurement. Approximately 20 percent of the initial energy is dissipated through irreversible processes associated with the propagation of the shock front. The acoustical energy measured in the bubble pulse pressure waves is found to be very much less than the total energy lost by the bubble during the same interval, as determined from period measurements. Finally, after the oscillations have effectively died down, it is found that approximately 10 percent of the energy has been expended in displacing the water to form a gas bubble. About 30 percent of the energy is unaccounted for, and no direct evidence as to the mechanism of the loss appears to be available. The values quoted apply specifically to TNT as the explosive.

* The study upon which these results are based was made at the Underwater Explosives Research Laboratory, Woods Hole Oceanographic Institution under contract with the Navy Department Bureau of Ordnance.

J5. Relation between the Limiting Line Phenomenon and the Kármán Transonic Similarity Theory. W. PERL, *Columbia University.*—Kármán has recently given a small-perturbation treatment of compressible potential flows in the transonic speed range.[1] A verification of this theory in the lower transonic range (subsonic free stream), analogous to Kármán's verification[1] in the upper transonic range (supersonic free stream), is offered by the theoretical pressure distribution calculations of references 2 and 3. In references 2 and 3 the highest subsonic free stream Mach number M_1 at which a continuous potential flow exists for a Kaplan profile of thickness ratio τ is found, for variable τ, to satisfy the relation $(1-M_1)/\tau^{\frac{1}{3}}=K$, where K approaches, for small τ, a constant limiting value of the order of magnitude one. The pressure coefficient at a fixed point on the profile is expressible as $c_p=\tau^{\frac{1}{3}}f(K)$. These relations agree with the Kármán theory. The potential limit Mach number M_1 is identified in reference 3 as the lowest Mach number for the appearance of the limiting line phenomenon. The calculations of references 2 and 3 also offer a similar verification of the Kármán theory under the condition of constant local Mach number at a fixed point on the profile. Finally, the small perturbation form of the method of reference 3 agrees in general with the Kármán similarity theory.

[1] Th. von Kármán, "Similarity law of transonic flow," J. Math. and Phys. **26**, 3 (1947).
[2] Carl Kaplan, "The flow of a compressible fluid past a curved surface," NACA ARR 3K02 (1943).
[3] W. Perl, "Calculation of compressible flows past aerodynamic shapes by use of the streamline curvature," NACA TN 1328 (1947).

J6. The Solitary Wave and Periodic Waves in Shallow Water. JOSEPH B. KELLER, *New York University.*—The equations for irrotational motion of an incompressible inviscid liquid with a free surface, over a rigid bottom and under the influence of gravity, are expressed in dimensionless form. The solution is expanded in powers of the ratio of the average depth to a typical horizontal dimension. It is found that the zero order terms in the expansions satisfy the equations of the non-linear shallow water theory, which were first obtained in this way by K. O. Friedrichs. For two dimensional motion over a horizontal bottom the only steady state solutions of these equations are the constant or piecewise constant, bore-like solutions. If the constant velocity is (g. depth)$^{\frac{1}{2}}$, the first order terms yield a two parameter family of periodic steady solutions similar to those of Korteweg and DeVries. When the wave-length in these solutions is infinite, they reduce to a one parameter family of solitary waves, similar to those of Rayleigh and Boussinesq. The present solutions yield more information and are physically more reasonable than the former ones, and have the added advantage of being obtained systematically. The method of obtaining higher approximations is perfectly definite, and the equations for the determination of the next approximation are given.

J7. Reflection and Transmission of Sound by a Spherical Shell. HERBERT B. KELLER AND JOSEPH B. KELLER, *New York University.*—A periodic point source in medium 1 is at the center of a spherical shell of medium 2 which is surrounded by medium 3. The densities, sound speeds and shell radii are arbitrary. For this case an exact, explicit expression for the sound pressure is obtained. If the shell radii become infinite but the thickness remains constant, and if media 1 and 3 are the same, the solution reduces to that of Rayleigh for plane waves normally incident on a flat plate. If the shell radii become infinite and if media 2 and 3 are the same, the solution yields the acoustic Fresnel formulae for normal incidence of a plane wave on a plane interface between two half-infinite media. For finite radii, with media 1 and 3 identical and the shell thickness small compared to a wave-length, a simpler form for the solution is obtained. This solution is found to agree with the approximate solution of H. Primakoff and J. B. Keller[1] for the sound fields reflected and transmitted by a thin shell of any shape, when their result is specialized to the present case.

[1] H. Primakoff and J. B. Keller, J. Acous. Soc. Am. **19**, 820 (1947).

J8. On the Resistance to Motion through Highly Rarefied Gases. M. HEINEMAN,* *Harvard University.* (Introduced by R. Courant.)—A general formula is derived, valid at all Mach numbers M in the region of free molecule flow (infinite mean free path L), for the momentum per second due to impinging molecules on a convex body of any shape. In order to obtain the total force, the momentum per second of the reflected molecules must also be computed. This is done for the cases of specular reflection and of diffuse reflection with accommodation. Numerical tables of the drag coefficient C_D as a function of M have been worked out for both types of reflection for the following cases: an inclined plate, a sphere, a cylinder moving perpendicularly to its axis, a cone moving parallel to its axis, and an ellipsoid, to its major axis. It is indicated how the force might be calculated when the collisions between the reflected molecules and the rest of the gas are no longer negligible as in the case of free molecule flow. The method consists essentially in finding an expansion in terms of

powers of $1/L$, for the velocity distribution function of the non-uniform gas.

* Now at New York University.

J9. On Supersonic Flow Patterns. M. M. MUNK, *Naval Ordnance Laboratory.*—In plans, supersonic, two-dimensional potential flows of a barotropic fluid reducibility of the equation for the reciprocal Legendre potential in the hodograph to the simple wave equation is associated with the absence of curvature of the Mach lines in the physical plane, and with tangency of the hodograph characteristics and the lines of constant direction of the conjugate characteristics. For perfect gases, this condition prevails at a Mach number given by $M^2=4/3-\gamma$; equal to 2.5 for air. In the neighborhood of that Mach number, drawing of the Mach line net is particularly simple. The criterion for straightness of Mach lines for other barotropic fluids is stated, and the expansion curve for a hypothetical barotropic fluid is derived having straight Mach lines throughout.

J10. On the Linearized Supersonic Flow through Ducts. ALEXANDER WEINSTEIN, *Naval Ordnance Laboratory.*—The paper gives an analysis of the flow due to the distribution of sources along a skeleton cylinder. The results are compared with the corrected Beltrami's formulas for the flow of an incompressible fluid (*cf.* A. Weinstein, Bulletin American Mathematical Society **52**, 240 (1946)), and with the computation of Mack, Ludloff and Weiche (Journal of Applied Physics **18**, 681 (1947)).

J11. On the Differential Equations for Slip Flow. C. TRUESDELL, *Naval Ordnance Laboratory.*—A fluid is defined as a continuum in which the dissipation function is a function of the following variables: a constant of dimension [mass]/[length][time]; a constant of dimension temperature; the mean pressure; the thermodynamic pressure, the temperature, the extraneous force, and their gradients up to (say) pth order; and finally the velocity gradients. The dissipation function is expanded in a power series in the velocity gradients of which each term is a power series in the gradients of the thermodynamic state. In the resulting expressions for the stress tensor terms involving tensors of rank 4 in the velocity gradients, tensors of rank 3 in products of the velocity gradients and state gradients, and tensors of rank 2 in the state gradients are retained. Expressions are then obtained for the stresses in slip flow of a rarefied gas which include those derived from kinetic theory by Burnett, Chapman-Cowling and Schamberg as a special case. The present derivation is based solely upon the principles of invariance, and therefore serves as a standard to which the results of a kinematic theory derivation must conform. The fact that the abovementioned kinematic theory derivation produces equations less general than those derived indicates that a number of special assumptions, of which the Stokes relation is one, lie hidden in the kinematic theory development. The mathematical nature and physical implications of these special assumptions are discussed.

J12. On Methods of Deriving Three-Dimensional Gas Flow Patterns from Plane Flows. P. NEMENYI and R. PRIM, *Naval Ordnance Laboratory.*—Two questions are investigated: (1) From a plane rotational or irrotational flow pattern how can a flow pattern be obtained, all three components of which are different from 0, but depend only upon two variables? This investigation is a generalization of that of Poritsky who solved the problem for the special case where the third component is uniform throughout the field. (2) From a plane irrotational flow pattern how can a rotational flow be constructed the velocity vector of which is everywhere parallel to a common plane but dependent on all three coordinates? The problem was solved for incompressible fluids by Massotti. The present authors generalize Massotti's analysis to compressible fluids and apply their result to the special case of flow in horizontal layers along a winding surface with straight horizontal elements.

J13. Extension of Crocco's Theorems to Flows Having Non-Uniform Stagnation Enthalpy. R. PRIM, *Naval Ordnance Laboratory.*—Crocco's theorems relating the vorticity and pressure along streamlines of plane and of axially symmetric steady gas flows are generalized to include flows having non-uniform stagnation enthalpy by a reformulation in terms of the vorticity of the reduced velocity field. It is shown that Crocco's stream-function equations for steady-plane and axially symmetric gas flows remain valid if the restriction to flows having a uniform stagnation enthalpy is removed.

J14. Spark Shadowgrams of Spheres at Supersonic Speeds in Water. J. HOWARD MCMILLEN AND R. L. KRAMER, *Naval Ordnance Laboratory.*—Spark shadowgrams have been taken of one-eighth inch steel spheres traveling through water at both transonic and supersonic speeds (above 5000 ft/sec). When a grid was placed between the sphere and the spark, the distortion of the grid shadow gave a qualitative picture of the pressure distribution around the sphere and in the region between the sphere and shock wave. At supersonic speeds, the usual concentration-of-light band which follows the absence-of-light band was replaced by a series of bands and fine lines covering an angular width of about 0.1 radian. By using masks to select beams from the spark, it was shown that these patterns were produced by rays passing near the shock-wave front. No simple optical explanation for these lines and bands, other than postulating certain pressure distributions within the shock wave, has been found. Spark shadowgrams were also obtained for fast spheres (7000 ft/sec) in air at Mach number 6.7. These showed temperature fronts paralleling the wake with the low temperature region on the trajectory side. Excitation of molecular vibration levels is offered as a possible explanation of these fronts.

J15. Measurement of Velocity Loss of Shocks Traveling in a Shock Tube. R. J. EMRICH, *Lehigh University* AND F. B. HARRISON, *Princeton University.*—The transits of a shock moving in a straight airfilled tube of 15-cm diameter

past four stations have been measured within errors of less than ± 0.1 μsec. For shocks whose velocities at 25°C vary from 355 to 435 m/sec, the losses in velocity over 2.5 meters vary from 0.05 to 0.2 percent; repeated measurements on shocks of equal strength show a variation in the velocity loss of about the same magnitude as the velocity loss itself. Calculations, using the Rankine-Hugoniot relations applied to a normal shock in a perfect gas and measured values of sound velocity, indicate that for propagation into air of 70 percent relative humidity at 25°C shocks of strengths $(p-p)/p$ between 0.05 and 0.68 suffer decreases in shock strengths per meter of travel of about 0.5 percent. Of over 100 shock velocities measured, none showed a decrease in shock strength of more than 1.2 percent per meter of travel. A knowledge of the amount of decrease permits calculation of conditions in the gas at some desired point in a shock tube from a velocity measurement made ahead of the point. This work was supported by the U. S. Navy.

FRIDAY MORNING AT 10:00

Horace Mann Auditorium

(W. SHOCKLEY presiding)

Solid State, Mostly Semiconductors

K1. Electrical Properties of Pure Silicon and Silicon Alloys. G. L. PEARSON AND J. BARDEEN, *Bell Telephone Laboratories.*—Electrical resistivity and Hall measurements have been made over the temperature range from 90°K to 900°K on pure silicon and on silicon alloys containing 0.0005 to 10.0 percent *P*-type impurity or *N*-type impurity. The resistivity curves in the intrinsic range indicate an energy level separation of 1.2-electron volts. In the transition region between the intrinsic and impurity ranges the Hall curves flatten and indicate that one free electron (or hole) is furnished by each impurity atom. The mobility and mean free path of both electrons and holes have been calculated as a function of temperature and impurity content. In the high temperature region where lattice scattering predominates the hole mobility is $5\times10^{5}T^{-\frac{1}{2}}$ cm²/volt-sec. and the mean free path is $2\times10^{-4}T^{-\frac{1}{2}}$ cm. At any given temperature the ratio of electron to hole mobility is 2.9. At lower temperatures the impurity atoms contribute to scattering so that the mobility and mean free path reach a maximum and decrease with further decrease in temperature as required by theory. In the impurity scattering region the mobility and mean free path are inverse functions of impurity content.

K2. Temperature Dependence of Work Function of Semiconductors. A. H. SMITH* AND P. H. MILLER, JR., *University of Pennsylvania.*—Samples of *P*-type and *N*-type silicon and of *N*-type germanium have been examined to determine the temperature dependence of the work function of these semiconductors as they are heated to near intrinsic temperatures. High temperatures of the semiconductors were obtained by passing current directly through the sample, and observations were made as the sample cooled. The method of determining change in work function was to observe the current *versus* voltage curves of photoelectrons emitted from a tantalum surface and arriving at the semiconductor surface. This experiment indicated negligible change in work function of semiconductors at high temperatures from that at 200°C. These results are consistent with the hypothesis of surface energy states. This work was supported in part by the U. S. Navy.

* Now at the University of Chicago.

K3. Deuteron-Bombarded Semiconductors.* K. LARK-HOROVITZ, E. BLEULER, R. DAVIS, AND D. TENDAM, *Purdue University.*—Pure germanium (resistivity of ~1 to 5Ω-cm) and *P*- and *N*-type germanium semiconductors have been bombarded with ~10-Mev deuterons. The resistivity of the pure samples decreases after bombardment. The resistivity of the *P*-type samples, measured both as bulk resistivity and as spreading resistance, also decreases. *N*-type samples show a tendency to a transformation into *P*-type, and the resistance, measured as spreading resistance, increases. These effects, observed immediately after bombardment, remain after the radioactivity of the sample has disappeared. Rectification and photo-effects change after bombardment with the change in sign of the carriers. From the measured radioactivity of the bombarded sample, the deuteron current and the number of recoils in the sample calculated from Coulomb scattering, the effect of new impurity centers, trapped hydrogen atoms, and lattice defects produced by recoil can be estimated.

* Assisted by Signal Corps and ONR contracts.

K4. Photoelectric Effects and Their Relation to Rectification at Metal-Semiconductor Contacts.* S. BENZER, *Purdue University.*—By illumination of a metal-semiconductor contact and observation of the photoelectric change in external current as a function of applied voltage, information may be obtained regarding the nature of the barrier layer. According to present rectification theories, a photocurrent flowing in the high resistance direction is expected at zero applied voltage, the photo-current saturating as voltage is applied in this direction. In the low resistance direction, the photo-current, which in this case is opposite to the dark current (photo-negative effect), should decrease

in magnitude, approaching zero as the applied voltage reaches the barrier height. In these experiments, millisecond pulses of light were focused on the contact, producing current pulses in a series resistor which were amplified and observed on an oscilloscope. The photo-current as a function of bias was obtained in this manner for contacts of metal *vs.* various specimens of Ge and Si, and for contacts of the semiconductors *vs.* each other. While the results resemble the theoretical expectations in some aspects, there are marked anomalies. A non-rectifying contact, for example, may show large differences in photo-effect in the two directions.

* This work was assisted by a Signal Corps contract.

K5. Galvanomagnetic and Thermomagnetic Effects in Tellurium.[1] WAYNE SCANLON AND K. LARK-HOROVITZ, *Purdue University.*—The transverse Hall e.m.f. may be masked by other galvanomagnetic or thermomagnetic effects which also contribute to the measured e.m.f. In tellurium, the transverse effects are unusually large and were found to alter significantly the true Hall effect. The longitudinal effects were also investigated but were found to be so small that they did not alter the measured Hall e.m.f. appreciably. The Nernst effect was found to pass through a maximum value at about 130°C and was negligibly small at temperature below 30°C and above 300°C. This effect was eliminated from the Hall effect data by averaging results with both direction of sample current. The Ettingshausen effect in tellurium was found to pass through a maximum value at about 160°C, and decreased rapidly to zero on either side of the maximum. The sign of the effect was positive throughout the region of temperatures investigated. Since the thermo-electric power was found to be positive throughout this temperature range, the Ettingshausen temperature difference produced an e.m.f. which was in the opposite direction to a positive Hall e.m.f. The maximum e.m.f. resulting from the Ettingshausen effect occurred in the region of temperatures where the apparent Hall coefficient showed the anomalous double reversal of sign from positive to negative and back to positive again. Upon correcting the Hall data for the Ettingshausen effect, no reversal of sign was observed.

[1] This work was supported by a Signal Corps contract.

K6. Theory of the Nernst and Ettingshausen Effects in Semiconductors at High Temperature.* V. A. JOHNSON AND K. LARK-HOROVITZ, *Purdue University.*—A large Ettingshausen effect exists in tellurium at high temperatures.[1] Earlier theories of galvanomagnetic and thermomagnetic phenomena in semiconductors are valid only in the impurity temperature range, whereas the present theory considers both electrons and holes. The Nernst coefficient, Q', is derived by calculating the transverse electric field, E, produced by thermal current flowing through a sample in a direction perpendicular to a magnetic field, H. The thermal current density, w, is evaluated under the assumption that there is no transverse temperature gradient, longitudinal electric field, nor transverse electric current. $Q'=E/(wH)$. The Ettingshausen coefficient P is calculated from the thermodynamic relation $P=Q'T$ and is expressed by quantities characteristic of the semiconductor:

$$\sigma\kappa P=\frac{9\pi kT}{16c}(n_1b_1^2+n_2b_2^2)+\frac{3\pi T^2}{8c}\left\{n_1b_1^2\frac{d}{dT}\left(\frac{\mu_1}{T}\right)+n_2b_2^2\frac{d}{dT}\left(\frac{\mu_2}{T}\right)\right\},$$

where σ, κ are electrical and thermal conductivities, n_1 number of electrons per cm^3, b_1 electronic mobility, μ_1 chemical potential for electrons, with subscript 2 pertaining to holes. The temperature behavior of P is in agreement with experiment.

* This work assisted by a Signal Corps contract.
[1] See preceding abstract.

K7. Temperature-Pressure-Conductivity Relations in Semiconductors. F. C. BROWN, *Cambridge 39, Massachusetts.*—Conductivity-temperature variations in semiconductors are interpreted as depending on number of electrons that have adequate thermal energy to enter conduction band against one or more field levels. The limited temperature range in selenium permits observation of only one level. Silicon and germanium have two. In hexagonal silicon crystals between room temperature and 400°K variation of conductivity is due to varying number of electrons having energy greater than 0.23 volt. With minute electrode contact area this value may vary because of nature of surface state with unbalanced electric field. Between 500°K and 1300°K the variation is largely due to the number of electrons having energy greater than 0.8 volt. By increasing pressure the work function is lowered for both levels. By pressure only at electrodes the low value work function can be reduced practically to zero, while conductivity through crystal lattice remains unchanged. Light sensitiveness corresponds to temperature effect. Thus radiation produces change of conductivity because of temperature rise at electrode contacts surfaces, and proportional to conductivity temperature coefficient. The proportional conductivity change by temperature (or radiation) is reduced by increased pressure, but within limits the absolute change of conductivity is increased by pressure.

K8. Structure and Conductivity in the VI$_b$ Group of the Periodic System.* A. VON HIPPEL, *Massachusetts Institute of Technology.*—In the sequence: oxygen, sulfur, selenium, tellurium, and polonium, a systematic change takes place from diatomic molecules, through ring and chain molecules, to a simple cubic lattice structure formed by atoms. This transition is paralleled by a modification in the electrical behavior from insulator (0, *S*), to semiconductor (Se, Te,) to metal (Po). The paper is concerned with this progressive change in structure and conductivity and with the interrelation of the two phenomena. It discusses first the stability of ring and chain molecules, considers next schematically the electronic conductivity of Se from the standpoint of the band picture, and, finally, suggests an alternative approach which connects structure and conductivity by extending qualitatively the concept of quantum-mechanical resonance from molecular structures to lattice structures.

* This work was supported by O.N.R.

K9. Frequency Spectrum of Noise in Crystal Rectifiers.* WILLIAM MILLER, *University of Pennsylvania.*—The noise

power generated by crystal rectifiers is found to have a $1/f$ spectrum for $10^2 < f < 10^6$ c.p.s.[1] A model has been investigated wherein noise represents a modulation of the crystal current by motion of impurity atoms in the semiconductor. The correlation function (hence the power spectrum) can be found by calculating probability after effects for the distribution of impurity atoms in the semiconductor, and then relating each distribution to a value of noise current. If one assumes that the noise is generated only by the impurity atoms in a thin layer near the surface of the semiconductor, then the calculated power spectrum is more complicated than the observed $1/f$ law, giving a $1/(f)^{\frac{1}{2}}$ dependence for $f \ll \lambda$, and $1/f^2$ for $f \gg \lambda$. (λ = average jumping frequency of an impurity atom.) The case of many layers, each with its own modulating factor, has been solved, but the result contains too many parameters to be useful at present without further assumptions.

* Assisted by the Office of Naval Research.

[1] P. H. Miller, Jr., Proc. I.R.E. Waves and Electrons **35**, 252 (1947)

K10. Theory of the Luminescence of Ionic Phosphors. FERD E. WILLIAMS,* *General Electric Company.*—The ionic radii of excited states of Tl^+ and Mn^{++} are computed approximately and, recognizing that the ions of a crystal are relatively incompressible compared to the lattice, potential energy curves are constructed for the normal and excited states of these ions in the KCl and ZnF_2 lattices, respectively. Corrections are applied for the Madelung, exchange repulsion, ion dipole, and van der Waals interactions. A single precise configuration coordinate, namely, the distance from the activator ion to the nearest neighbor, is used for all potential energy curves, but various assumptions are made as to the behavior of the rest of the lattice for different processes. To compute peak absorption and emission energies it is shown to be reasonable and to result in moderately good agreement with experiment to assume that the entire lattice expands freely to accommodate the activator in whatever state it exists, whereas to compute the activation energy for the competing radiationless recombination, it is assumed that the next nearest neighbors are held rigid. A new origin of electron traps is suggested. On the basis of the analysis several criteria for luminescence are cited, and several significant experiments are proposed.

* Also Assistant Professor of Chemistry, University of North Carolina, Chapel Hill, North Carolina.

FRIDAY MORNING AT 9:30

Pupin 301

(R. J. SEEGER presiding)

Joint Symposium of the Fluid Dynamics Committee and the Institute of Aeronautical Sciences

Physics of Rarefied Gases

L1. Physics of Rarefied Gases. I. ESTERMANN, *Carnegie Institute of Technology.* (30 min.)

L2. The Temperature of a Highly Rarefied Gas. LYMAN SPITZER, JR., *Princeton University.* (30 min.)

L3. The Propagation of Sound in Air at Low Pressures. R. B. LINDSAY, *Brown University.* (30 min.)

L4. Friction and Heat Conduction in Rarefied Gases. K. F. HERZFELD, *Catholic University of America.* (30 min.)

L5. On the Theory of the Transport Phenomena in Rarefied Gases. G. E. UHLENBECK, *University of Michigan.* (30 min.)

FRIDAY MORNING AT 9:30

Havemeyer 309

(C. M. SLACK presiding)

Invited Papers of the Division of Electron Physics

M1. Some Considerations Concerning Theories of the Oxide Cathode. CONYERS HERRING, *Bell Telephone Laboratories.* (40 min.)

M2. The M.I.T. Electron-Physics Programme: Past, Present and Near Future. W. B. NOTTINGHAM, *Massachusetts Institute of Technology.* (40 min.)

M3. Spectral Distribution of the External Photoelectric Yield from Semi-Conductors. L. APKER, *General Electric Company.* (25 min.)

M4. Secondary Electron Emission from Insulators. J. B. JOHNSON, *Bell Telephone Laboratories.* (40 min.)

FRIDAY MORNING AT 10:00

McMillin Theatre

(P. M. MORSE presiding)

Apparatus of Nuclear Physics

O1. Design Study for a 10-Bev Proton Synchrotron. M. STANLEY LIVINGSTON, *Brookhaven National Laboratory.**—The threshold for the production of pairs of nucleons by protons is believed to be 5.6 Bev,[1] and a preliminary design figure of 10 Bev has been chosen for the Brookhaven Accelerator Project. Orbit radius required for 10-Bev protons at 15 kilogauss is 80 ft., and economy prescribes a ring magnet and synchrotron acceleration. At 4-Mev injection energy the frequency is 180 kilocycles; at 10 Bev it is 2.0 megacycles. Such low frequencies allow pulse techniques for injection and ejection. Allowing 1 sec. for acceleration, the average voltage per turn is 5500 volts. Aperture requirements ion oscillations suggest a magnet gap 4 ft. wide and 1 ft. long, with a doughnut vacuum chamber between poles. The vacuum requirements to reduce gas scattering during acceleration are within practical limits. A "*C*" magnet constructed of ½-inch laminations to reduce eddy current losses will have 5×10^7 joules stored energy; rotating machinery and flywheels can reutilize stored energy and reduce power requirements. The frequency-modulated accelerating system may require straight sections and a "racetrack" magnet design. Model studies and component designs are in progress.

* Research carried out under the auspices of the Atomic Energy Commission.

[1] Feshbach and Schiff, Phys. Rev. **72**, 254 (1947).

O2. Induction Accelerator for a Proton Synchrotron. JOHN P. BLEWETT, *Brookhaven National Laboratory.**—The radiofrequency accelerating system for the proposed Brookhaven proton synchrotron must supply an average 5500 ev of energy per revolution to the ion beam, and must operate over the frequency range 180 kc to 2000 kc. Resonant structures of the sort used in electron synchrotrons would be very large and extremely difficult to tune over the frequency range. If operated untuned their impedance levels would be unreasonably low, calling for circulating currents of thousands of amperes. Higher impedance levels are attainable, however, in a "transformer" type of accelerating system. In one of the straight sections of a racetrack a ferromagnetic core surrounds the vacuum envelope. A winding on the core serves as primary, and the ion beam is the secondary. Reasonable impedance and power levels over the frequency range result from this procedure. The core will include several tons of laminated or powdered ferromagnetic material. Appropriate choices of dimensions and materials will be presented, and driving circuits will be discussed.

* Research carried out under the auspices of the Atomic Energy Commission.

O3. Ion Orbit Control for a Proton Synchrotron. G. K. GREEN, *Brookhaven National Laboratory.**—The magnetic guiding field of a proton synchrotron is shaped so as to provide stability in the vertical and radial betatron oscillations. Superposed on these "free" oscillations are the slow synchrotron oscillations, in phase and radius. The ion orbit oscillations set a lower limit on the doughnut aperture and consequently affect the magnet gap size and the magnet cost. In order to minimize the amplitude of the oscillations, to prevent particle loss by striking the walls, the injection must be very precisely controlled—and then the accelerating radiofrequency and magnetic field must be precisely synchronized. Three basic control methods are considered —programming, data computing, continuous control—of which a combination is indicated. Continuous control by means of pick-up electrodes can be applied to regulate the radiofrequency and to indicate the radial position of the beam. Computations indicate that stable control can be achieved. Various schemes will be tested in a 40-inch electron model, scaled to the proton velocities of a 10-Bev machine.

* Research carried out under the auspices of the Atomic Energy Commission.

O4. Magnetic Circuit for a Proton Synchrotron. WM. H. MOORE AND JOHN P. BLEWETT, *Brookhaven National Laboratory.**—Calculations have been made for a 10-Bev proton synchrotron magnet, considering both air core and iron core types. The air core magnet requires an unreasonably high stored energy and presents very difficult problems of mechanical support and fabrication. A new iron core magnet design uses shaping of the field coils to assist in maintaining the desired field configuration. The magnet is a poleless *C* structure open on the side farthest from the center. This will allow easy access for pumps and injection systems and will facilitate ejection of the accelerated protons. The poleless structure is economical in its iron requirements, since the return path for the flux is kept to a minimum. Electrical and magnetic characteristics will be described. A six degree arc of the magnet will be modelled at ¼ scale to confirm the conductor location and pole face shaping.

* Research carried out under the auspices of the Atomic Energy Commission.

O5. A Microwave Accelerator for Production of High Intensity Gamma-Rays. G. A. KOLSTAD, H. L. SCHULTZ, AND C. G. MONTGOMERY, *Yale University.*—Photo-nuclear disintegration experiments require intense monochromatic gamma-ray sources to bring the counts observed well above background. A microwave accelerator has been designed

and is being built for this purpose. A coaxial re-entrant cavity of copper-plated steel has been designed to resonate at 50 megacycles with a Q of 1.9×10^4 and a shunt resistance of 1.3 megohms. A 60-cycle a.c. resonance-charging spark-gap modulator forms pulses of 20 kilovolts and 250 microseconds in length. This pulse power of 1 megawatt drives a tuned-plate, tuned-grid, parallel-line oscillator which uses two Machlett ML-880 tubes. The radiofrequency pulses are magnetically coupled out of the oscillator and into the cavity through a coaxial line. The ions are to be formed by a source within the inner conductor and accelerated across a 1-inch gap by radiofrequency voltages of about 1.5 Mev. The short gap makes possible a high beam intensity, since focusing is unnecessary. The $Li^7(p,\gamma)\,2\,He^4$ reaction should yield a 17-Mev gamma-ray intensity of about 10^8 or 10^9 per second if 100 milliamperes average ion current can be obtained. A high current ion source is being constructed similar to the one described by Finklestein.[1]

[1] A. T. Finklestein, Rev. Sci. Inst. 11, 94 (1940).

O6. Preliminary Studies of Operation of the Yale Linear Electron Accelerator.* H. L. Schultz, J. A. Lockwood, R. L. McCarthy, and P. J. Rice, *Yale University.*—Results of preliminary experiments using a single cavity resonator will be reported.[1] Electrons were injected at low energy into a seven inch long cylindrical cavity operating in the TM_{010} mode with peak r-f input power in excess of 500 kw. Using a thin lens beta-ray spectrometer, the energy spectra of emergent electrons under varied conditions of excitation power and injection voltage have been measured. Special problems associated with r-f circuit design will be discussed.

* Work assisted by the Office of Naval Research.
[1] Phys. Rev. 72, 346 (1947).

O7. The Clinton Pile Oscillator. J. I. Hoover, W. H. Jordan, C. D. Moak, L. A. Pardue,* H. Pomerance, J. Strong,** and E. O. Wollan, *Clinton National Laboratory.*—The pile oscillator is an instrument for measuring thermal neutron absorption cross sections. In the form used here, it consists of a small beryllium boat which is made to oscillate in the region of the graphite reflector of a pile, with an amplitude of about 15″ and a frequency of about 1 cycle per second. At the middle of the stroke the boat passes along the axis of a cylindrical boron-coated ion chamber. The depression of the neutron flux in the vicinity of the absorber produces an alternating current in the ion chamber which is then amplified, rectified, and integrated. The absorption cross section of an unknown sample is determined by comparing the charge accumulated in the integrating circuit with that obtained by a standard gold absorber. The instrument will detect a total absorption cross section of about 10^{-3} cm². One of the major difficulties in making this instrument reliable for absorption measurements has been that of eliminating the effects of scattering by the sample. In the present instrument no correction for scattering is necessary when the absorption cross section is greater than 1 percent of the scattering cross section.

* Now at the University of Kentucky, Lexington, Kentucky.
** Now at University of California, Berkeley, California.

O8. Helical Focusing Beta-Ray Spectrograph. C. S. Wu, W. W. Havens, Jr., R. Albert, and G. Grimm, *Columbia University.*—The solenoidal type beta-ray spectrograph of Columbia University has been re-installed for the investigation of beta-disintegration. Many components of this instrument have been redesigned in order to extend the study of the beta-spectra to very low energies. The counter used in connection with this work has an extremely thin collodion film, 0.1μ thick, supported by a metal grid. To reduce the pressure difference on the thin window, the counter is filled with alcohol vapor only. The characteristics and efficiency of the counter *vs.* alcohol vapor pressure for electrons of various energies have been carefully investigated. In order to distinguish between electrons and positrons, a simple modified baffle system has been used and is found to transmit particles of one sign only, introducing no detectable scattering. An electronic voltage regulator has been designed and built to regulate the current in the solenoid to within 0.3 percent of the fluctuations over a long period of time in the range from a few amperes to 600 amperes.

O9. The Focusing in Crossed Fields of Charged Particles at Relativistic Energies. Walter E. Millett, *Harvard University.*—The focusing of charged particles in crossed cylindrical electric and uniform magnetic fields, as formulated by Henneberg,[1] has been extended to include relativistic velocities. Where y equals the ratio of the electric to the centrifugal acceleration for the circular orbit $r=r_0$, the focusing angle $\Phi=\pi/(1+y^2(1-\beta^2))^{\frac{1}{2}}$ which for fixed $y\neq0$ diverges from classical values ($\beta\ll1$) by significant amounts for energies above ten percent of the particles' proper energy. The line width for a half-angle of divergence α is

$$B=-\alpha^2r_0\frac{1+\frac{1}{2}y+y^2+3y^3+\frac{1}{2}y\beta^2(2-3y-7y^2)-\frac{3}{8}y^3\beta^4}{[1+y^2(1-\beta^2)]^2},$$

and the velocity dispersion

$$D=2r_0\frac{1+y}{1+y^2(1-\beta^2)}.$$

For the achromatic case $y=-1/1-\beta^2$. y has its usual values for the Wien, electric, and magnetic cases.

[1] W. Henneberg, Ann. d. Physik 19, 335 (1934).

O10. Detection of Beta-Rays by Scintillations. George B. Collins and Rosalie C. Hoyt, *University of Rochester.*—The 1P21 photo-multiplier tube has been used in a manner similar to that described by Marshall and Coltman[1] to detect scintillations produced in various substances by beta-rays. The objective is a fast counter for low ionizing particles. A fast oscilloscope and amplifier with a resolving time of the order of 5×10^{-7} second was employed. $BaSO_4$+5 percent $PbSO_4$, anthracene, naphthalene, and diphenyl, when bombarded with beta-rays from radium, produced pulses on the oscilloscope whose maximum height was 15 to 7 times noise. The shapes of the individual pulses were observed on the oscilloscope by means of a triggered sweep and a delay line. These shapes appeared to be fully ex-

plained in terms of the response time of the electrical circuit. It thus appears that the light emitted by these substances, following excitation by a beta-particle, occurs in a time less than 5×10^{-7} second, except for possible long period fluorescence with $\tau>5\times10^{-5}$ second which would not be observed. Under α-ray bombardment, ZnS and ZnO were found to decay in 5×10^{-6} second. Great differences were observed in the relative responses of various substances to alpha- and beta-rays. This work was supported by the Office of Naval Research.

[1] Fitz-Hugh Marshall and J. W. Coltman, Phys. Rev. **72**, 528 (1947).

O11. Correlated Probabilities in Multiple Scattering.* W. T. SCOTT, *Smith College* AND H. S. SNYDER, *Brookhaven National Laboratory.*—We have used Fermi's distribution function for the scattering-produced probability of a certain lateral displacement, y, and a certain angular deflection, θ, of a particle passing through a length, t, of the gas of a cloud chamber,[1] to calculate the distributions of several quantities, including the following: θ at point P when the particle is known to pass through points P and Q, or through P, Q, and R; y at t' beyond Q for known passage through P and Q, and consequently the distribution in apparent curvature when observed at three points[2]; y at t' beyond R for known passage through P, Q, and R; curvature C_b of points Q, R, S for known C_a of points P, Q, and R (S either between Q and R or beyond R); the ratio C_b/C_a (both C_b and C_a variable, with S beyond R); the reduction in scattering error made by observing at 4 points (a factor $(15/16))^{\frac{1}{2}}$; the difference C_b-C_a. Results confirm and extend those of Bethe.[2] We find the ratio of C-type curves to S-type to be 1.4. Calculations on an accurate inclusion of the Born-approximation scattering law will be reported.

* This work was carried out at the Brookhaven National Laboratory under contract with the U. S. Atomic Energy Commission.
[1] See B. Rossi and K. Greisen, Rev. Mod. Phys. **13**, 267 (1941).
[2] H. A. Bethe, Phys. Rev. **70**, 821 (1946).

FRIDAY AFTERNOON AT 2:00

McMillin Theatre

(J. R. OPPENHEIMER presiding)

Retiring Presidential Address

P1. Electron Emission from Metal Surfaces: A Review. L. A. DUBRIDGE, *California Institute of Technology.*

Invited Papers

P2. Plans for the Brookhaven National Laboratory. P. M. MORSE, *Brookhaven National Laboratory.* (45 min.)

P3. Memorial Address in Honor of Max Planck. JAMES FRANCK, University of Chicago. (30 min.)

FRIDAY AFTERNOON AT 4:15

McMillin Theatre

(L. A. DUBRIDGE presiding)

Business Session of the American Physical Society

FRIDAY EVENING AT 7:00

Grand Ballroom, Hotel New Yorker

(L. A. DUBRIDGE presiding)

Dinner of the American Physical Society

The physicist and the future development of atomic energy. R. F. BACHER, *U. S. Atomic Energy Commission.*

SATURDAY MORNING AT 9:30

Havemeyer 309

(J. B. JOHNSON presiding)

Invited Papers of the Division of Electron Physics

Q1. The Separation of Isotopes in Quantity by Electromagnetic Means. LLOYD P. SMITH, *Cornell University.* (40 min.)

Q2. Conductivity Induced in Insulators by Electron Bombardment. K. G. MCKAY, *Bell Telephone Laboratories.* (40 min.)

Q3. General Characteristics of Phosphors. H. W. LEVERENZ, *RCA Laboratories.* (40 min.)

Q4. Some Physical Properties of Infra-Red Phosphors. W. L. PARKER, *Polytechnic Institute of Brooklyn.* (40 min.)

SATURDAY MORNING AT 9:30

Horace Mann Auditorium

(R. SMOLUCHOWSKI presiding)

Solid State, Including Ionic Crystals

R1. Self-Diffusion of Sodium in Sodium Chloride.* DILLON MAPOTHER** AND ROBERT MAURER, *Carnegie Institute of Technology.*—The self-diffusion coefficient of sodium in sodium chloride has been measured within the temperature interval of 350°C to 700°C. The diffusion coefficient may be represented by the equation

$$D = D_0 \exp(-\epsilon/kT)$$

for temperatures greater than 550°C. The values of the constants D_0 and ϵ are 3.13 cm²/sec. and 1.80 ev. Below 550°C the diffusion coefficient may be represented by the same equation, but the values of D_0 and ϵ are 1.6×10^{-5} cm²/sec. and 0.77 ev. The diffusion coefficient was measured by evaporating Na^{24} in the form of the chloride on a face of a single crystal of sodium chloride. After diffusion had proceeded for a known time at a known temperature the distribution of beta-activity within the crystal was determined. A comparison of measured diffusion coefficients with coefficients calculated from electrolytic conductivity data will be presented.

* This work was supported in part by the Office of Naval Research.
** duPont Fellow in Physics.

R2. Calculation of the Binding Energy of Self-Trapped Electrons in Potassium Chloride. KENNETH E. KEYES, *Carnegie Institute of Technology.*—A calculation of the binding energy of Landau's self-trapped electrons in potassium chloride was made assuming that the "potential hole" created by the distortion of the lattice is $V(r) = -(1/K_0 - 1/K)e^2/r$, where $r \geq a$, and

$$V(r) = -(1/K_0 - 1/K)e^2/a = V_e = V_K - V_{K_0}$$

when $r \leq a$, where V_K represents the potential energy at the trapping center due to the surrounding dipoles, and V_{K_0} represents the potential energy at a positive ion surrounded by undisplaced dipoles. V_K and V_{K_0} were calculated using methods developed by Mott and Littleton.[1] Since the ionic displacements depend on the average field of the trapped electron, we calculated a family of wave functions for a number of assumed values of V_e. From each wave function a value of V_e may be computed. Then a plot of the difference of the initial and final values of V_e *versus* the initial value of V_e determines V_e and therefore the binding energy. This binding energy turned out to be such that the absorption band due to the self-trapped electrons would lie in the near infra-red.

[1] N. F. Mott and M. J. Littleton, Trans. Faraday Soc. **34**, 485 (1938).

R3. Binding Energy for a Self-Trapped Electron in NaCl.* J. J. MARKHAM, *University of Pennsylvania* AND F. SEITZ, *Carnegie Institute of Technology.*—A calculation (based on Born's theory of ionic crystals) has been made of the binding energy of a self-trapped electron in NaCl. The potential well, caused by the ionic displacements, was assumed to be a sawed-off Coulomb field, the sides being given by $(1/K_0 - 1/K)$, where the K's are the dielectric constants. The depth of the well was calculated by the method of Mott and Littleton. Here, however, we require a self-consistent solution, i.e., the initial wave function assumed to calculate the depth of the hole must be identical to the one obtained by the variational method. The electron is smeared over a sphere whose radius equals approximately three interatomic distances. The outer displacements are

calculated by a semicontinuum theory while the dipole on the three nearest ions are calculated from the conditions of equilibrium. The optical dissociation energy is 0.56 ev, whereas the thermal energy is 0.14 ev. The second value presumably explains why self-trapping has not been observed to date. The above energy should be about 1.5 times larger in LiF. These results suggest that self-trapping should be sought for at very low temperatures.

* This work was supported in part by Navy contract with the University of Pennsylvania.

R4. Activation Energy for the Migration of Paired Vacancies in KCl. G. J. DIENES, *Bakelite Corporation* AND FREDERICK SEITZ, *Carnegie Institute of Technology.*—The experiments of Leivo, Estermann, and Stern, on the changes in darkening and in density of KCl under intense x-ray irradiation, show that vacancies diffuse into the lattice at room temperature at a rate which indicates that the activation energy for diffusion of the migrating entities must be of the order of 0.5 ev or less. Since the activation energies for migration of isolated ion vacancies is considerably larger than this, it has been suggested by Huntington that the migrating units could be coupled pairs of positive and negative ion vacancies which assist one another in a manner similar to that proposed by Johnson and Wagner for diffusion of a solute atom in substitutional alloys. In the present calculation the activation energy for migration of a pair of vacancies is calculated on the basis of the Born theory of ionic crystals. The calculations resemble closely those carried out by Mott and Littleton on the formation and migration of single vacancies. It is found that the activation energy for migration of the pair is about 0.38 ev. The calculation error is estimated at about 10 percent. It is possible, however, that the repulsive potentials employed in the calculation are in larger error than this. The theoretical calculations do not contradict the viewpoint that the vacancies migrate in the form of pairs.

R5. Domain Structure and Electric Response of Barium Titanate Single Crystals.* B. T. MATTHIAS AND A. VON HIPPEL, *Massachusetts Institute of Technology.*—$BaTiO_3$ single crystals have been grown and investigated microscopically, with x-ray diffraction and in their dielectric and piezoelectric response. It is possible to see directly the domains of the ferroelectric crystals and to change their number, size, and orientation. Wall displacements and the alignment of such domains, for which well-known indirect evidence exists in the case of ferromagnetics, have now been observed directly in both polarized and unpolarized light, and the influence of electric fields, temperature, and pressure have been studied. Untwinned crystals consisting of very few domains have been made, and their dielectric and piezoelectric response has been measured without and with biasing voltage. Conclusions can be drawn about the formation of the electric dipoles in the $Ti\text{-}O_6$ octahedra and about their mutual coupling. The crystals are not tetragonal below the Curie point.

* This work was supported by O.N.R.

R6. Volume Electrostriction in Barium Titanate Ceramics. HANS JAFFE, *The Brush Development Company.*—The electrostrictive effects in barium titanate ceramics were studied by measuring the strain produced by strong alternating fields, and, conversely, the charge flowing onto a biased titanate plate when a stress was applied. It was found that barium titanate expands in the direction of the applied field and contracts in all directions at right angles to the applied field. The coefficient for the lateral contraction is about one-third of that for the parallel expansion. The volume change is given by the parallel expansion minus twice the lateral contraction. In case of an electric signal applied parallel to a bias d.c. field or a prepolarizing field previously applied,* there is a linear term in the relation between volume change and applied signal; correspondingly, a piezoelectric effect is observed if a hydrostatic pressure is applied to biased or prepolarized material. This piezoelectric effect is easily observed on titanate bodies immersed in oil subjected to alternating pressure, and serves conveniently as an indication of the piezoelectric activity of titanate ceramics in various states of previous electric treatment. A typical value for the hydrostatic piezoelectric constant, d_h, of prepolarized barium titanate is $50 \cdot 10^{-12}$ coulomb/newton.

* S. Roberts, Phys. Rev. **71**, 890 (1947).

R7. On the Anomalous Dielectric Behavior of $BaTiO_3$ Near 0°K. J. M. RICHARDSON, *Bell Telephone Laboratories.*—The dielectric constant ϵ of $BaTiO_3$ has been measured by B. Wul[1] down to about 2°K. The temperature coefficient $d\epsilon/dT$ remains more or less constant as the temperature is dropped from, say, 100°K down to about 5°K, below which it begins to approach zero as required by the third law. On the basis of $\epsilon \sim 100 (T \sim 0°\text{K})$ and reasonable assumptions about the effective charges and masses associated with the important normal modes in the polarization process, one estimates that the acoustical branches and some of the low frequency optical branches of the frequency spectrum will possess characteristic frequencies, at least one of which corresponds to a characteristic temperature $\Theta (= kT/\nu)$ of about 10°K. A theory of $d\epsilon/dT$ similar to Born's[2] theory of pyroelectricity shows the decrease becoming pronounced at $T \sim \frac{1}{3}\Theta$.

[1] B. Wul, J. Phys. **10**, 64 (1945).
[2] M. Born, Rev. Mod. Phys. **17**, 245 (1945).

R8. Breakdown Directions in Lithium Halide Crystals. J. W. DAVISSON, *Massachusetts Institute of Technology.*—Electrical breakdown paths in lithium halide crystals form star patterns which consist of 12 paths of the type $[xxy]$ where $x \geqslant y$. The paths lie within those acute sectors of the (110) planes bounded by the directions [110] and [111]. The star assumes the [110] orientation at low and tends to approach [111] with increasing temperature. Complex $[xxy]$ patterns showing radical changes in orientation of the paths as they proceed through the crystal, but following a definite sequence of directions, are obtained under excess voltage conditions. Although the breakdown paths apparently mark those directions for which electrons can be most rapidly accelerated by the applied field to

the ionization potential of the lattice, it is shown that the star paths do not follow simply from an electron wave interaction with the lattice or from a statistical competition between the [110] and [111] directions.

* This work was supported by O.N.R.

R9. Low Frequency Dispersion in Ionic Crystals.* R. G. BRECKENRIDGE, *Massachusetts Institute of Technology.*—A new region of anomalous electrical response has been observed at low frequencies in ionic crystals that have been treated to introduce relatively large numbers of lattice defects. The crystals thus far studied include various alkali halides and silver chloride. The effect is attributed to a jumping of the positive ions to vacant lattice sites under the influence of the applied field. This jumping is observed as an anomalous dispersion, producing a change in the dielectric constant which is small and frequently within the limits of error of measurement, and an associated peak in the dielectric loss tangent which is readily measurable. This maximum of $\tan\delta$ has been studied both as a function of frequency at a fixed temperature and as a function of temperature at fixed frequency. From the magnitude of the peak and position on the frequency or temperature scales it is possible to calculate the number of lattice defects present in the sample and the activation energy for diffusion U of the positive ion in the crystal. A knowledge of U allows a separation of the activation energy for conduction, $(W/2)+U$, into its components, thus determining $W/2$, the activation energy for hole formation.

* This work was supported by O.N.R.

R10. Some Characteristics of Bridges and Arcs between Separating Metallic Contacts. G. F. HULL, JR. AND H. SALTZMAN, *Dartmouth College.**—When metallic contacts carrying a current are separated, the contact may be bridged by a very small globule of metal, following which an arc may be formed. From cathode-ray oscillograms of the voltage across separating contacts, minimal length arc characteristics for gold and for platinum have been obtained, which lie between those found by Ives and Fink.[1] For currents and voltages below the minimal length arc characteristics metallic bridges are drawn out between the separating contacts. Oscillograms of these bridges show a rise in voltage to 0.42 volt, followed by a second rise to 0.9 volt for gold, and for platinum a rise to 0.65 volt and then to 1.44 volt. These voltages correspond to within 1 percent of the melting and boiling temperatures of gold and platinum, respectively, as given by contact theory.[2] These oscillograms also show evidence for the existence of transient arcs below the minimal length arc characteristics. Examination of all the oscillograms which contain arcs (about 800 in all) shows that an arc is always preceded by the formation of a metallic bridge. This suggests that the initial metallic vapor for the arc discharge is formed by the evaporation of a bridge.

* Assisted by the Office of Naval Research.
[1] H. E. Ives, J. Frank. Inst. **198**, 437 (1924). H. P. Fink, Wiss. Veröff. a.d. Siemens-Werk **17**, 45 (1938).
[2] R. Holm and E. Holm, Wiss. Veröff. a.d. Siemens-Werk **7**, 217 (1929).

R11. Anomalous Plastic Deformation in Brass and Aluminum. ANDREW W. MCREYNOLDS, *University of Chicago.*—The curve for stress *vs.* strain in solids is usually found smooth, with slope constant in the elastic range and uniformly decreasing in the plastic range. Such deformation is explained as the sum of a large number of small independent slips. Measurements on 70-30 copper-zinc and 2S aluminum, made at room temperature and slow constant loading rate, show that deformation proceeds in steps of rapid flow followed by only elastic strain. Height and length of steps are approximately uniform, 270 p.s.i. and 0.0005 strain, respectively, in aluminum, and are independent of rate of loading over a wide range. The phenomenon is dependent on temperature and has been found not to occur in 2S aluminum below $-50°$C, nor in tests on copper, cadmium, and 99.99 percent aluminum at 20°C. Further tests indicate that the horizontal portions of the steps occur as the propagation of a wave of deformation through the stressed regions, and thus represent a cooperative effect between grains rather than the sum of independent slips. Consequent hardening of the entire lattice prevents plastic flow until arrival of another wave, and results in the vertical portions.

R12. The Photoelastic Constants of Cubic Crystals. E. BURSTEIN, P. L. SMITH, AND B. HENVIS, *Naval Research Laboratory.*—The stress-optic constants, Π_{ij}, of a number of alkali halides, MgO and TlCl, were determined by a combination of static[1] and ultrasonic diffraction measurements.[2] The latter was also employed to obtain the elastic constants of TlCl. The strain-optic constants, p_{ij}, were then calculated from Π_{ij} and the elastic constants, s_{ij}. Previous photo-elastic data have only been completely reported for NaCl, KCl, CaF_2, and diamond. The results will be discussed in terms of Mueller's theory of the photoelastic effect of cubic crystals.[3] The theory, however, requires a knowledge of the ionic oscillator strengths and the change in ionic polarizability with strain. Since such information is not available, the results can only be compared qualitatively with the predictions of the theory. Preliminary results on a number of other cubic crystals will also be reported.

[1] K. Banerjee, Ind. J. Phys. **2**, 195 (1927).
[2] H. Mueller, Zeits. f. Krist. (a) **99**, 122 (1938).
[3] H. Mueller, Phys. Rev. **47**, 947 (1935).

R13. Further Studies of the Rupture of Metal Foils. WALLER GEORGE, *Naval Research Laboratory.*—The mechanism of the rupture of notched metal foils under constant tensile load has been reviewed previously.[1] Generally, the process consists of the slow elongation of the notch normal to the direction of the applied tensile load until a critical length is reached. At this point the crack velocity increases rapidly. The critical length is shown to be influenced by certain grip designs. Rigid gripping systems minimize these head-controlled instabilities. The effect of a threefold change in scale of the areal dimensions of the system is reported, using rigid grips with the specimen and head thicknesses being kept constant. The areal size effects obtained are compared with volume size effects found in

slow bend tests by workers at the University of North Carolina,[2] in terms of the work required per unit extension of the fracture.

[1] W. George and G. Irwin, Bull. Am. Phys. Soc. 1947 (Chicago meeting).
[2] P. Shearin, Proc. Bristol Conference, May 1947 (to be published Proc. Phys. Soc.).

R14. Application of the Method of Least Squares to X-Ray Crystal Structure Analysis.* W. J. TAYLOR, *The Ohio State University.*—The method of least squares has been applied to the refinement of atomic coordinates in x-ray crystal structure analysis by Hughes,[1] who, however, proceeded by numerical methods. In the present study the normal equations of least squares theory are obtained in an analytical form suitable for crystal structure analysis. The special equations applicable to the translation or rotation of a molecule or group of atoms as a rigid unit within the unit cell are derived. The method of least squares is compared with the method of steepest descents recently proposed by Booth.[2] It is shown that the least squares method is of general applicability, not only for the refinement of atomic coordinates in the final stages of the analysis, but also to at least some extent as a substitute for the trial-and-error method in the initial stages of the analysis.

* Supported by the Office of Naval Research.
[1] E. W. Hughes, J. Am. Chem. Soc. **63**, 1737 (1941).
[2] A. D. Booth, J. Chem. Phys. **15**, 415 (1947).

R15. The Two Ways of Aging. HERBERT M. MEYER, *Newark, New Jersey.*—For twenty-five years the question has not yet been answered as to whether age-hardening is caused by a single, continuous phenomenon (precipitation of the secondary phase) or by two phenomena (distortion within the matrix at lower aging temperatures, and precipitation at higher temperatures). Merica advanced first the hypothesis of "critical dispersion" of secondary CuAl particles; Fraenkel suggested "cold and warm aging;" Honda assumed distortion of the solid solution (by means of an interlocked, strained structure) previous to precipitation. Two trends have developed so far: in Europe the writer and others confirmed Honda's hypothesis. Preston and Guinier detected with new x-ray methods minute inhomogenities forming upon preferential planes within the matrix, and at higher aging temperatures a local superlattice was observed before the metastable transition structure appears. This structure as well as the connection between the Widmanstaetten figures and precipitation upon preferential lattice planes were studied by Fink, Mehl and others in this country. Here the main school of thought returned to Merica's original "simple hypothesis," after microscopic particles had been observed at early aging stages; but these particles are not real (Gayler). Aging actually develops along two distinct ways according to temperatures applied, and both ways eventually may lead to precipitation.

SATURDAY MORNING AT 9:45

Pupin 301

(L. A. DUBRIDGE presiding)

Low Temperature Physics and Isotope-Separation

S1. Distribution of He^3 Between Liquid and Vapor He^4.* HENRY A. FAIRBANK AND C. T. LANE, *Yale University,* AND L. T. ALDRICH AND ALFRED O. NIER, *University of Minnesota.*—The relative abundances of He^3 in the liquid and vapor phases of atmospheric helium have been studied as a function of temperature above and below the λ-point. The relative abundance of He^3/He^4 in the vapor (C_v) was determined by means of the mass spectrograph and the corresponding quantity for the liquid (C_L) computed from C_v and the mass balance and composition balance equations. From 5.2°K to the λ-point the ratio C_v/C_L increases as the temperature decreases, whereas below the λ-point this ratio sharply decreases to zero, showing that the vapor in equilibrium with superfluid helium contains no measurable amount of He^3. On the basis of these results a simple method of concentrating He^3 is suggested.

* The work at Yale University was assisted by the Office of Naval Research and that at the University of Minnesota by grants from the Research Corporation and the Graduate School.

S2. Experiments on the Isotopic Properties of Helium in the Liquid Phase.* J. G. DAUNT, R. E. PROBST, AND H. L. JOHNSTON, *Ohio State University.*—Experiments have been carried out on the process of filtration[1,2] of the rare isotope He^3 by superfluid flow through supra-surface films in contact with liquid helium II, using varying initial concentrations. Such films have been made to form semi-permeable membranes between two reservoirs of liquid helium II, permitting a flow of the He^4 isotope only (and allowing the formation of an osmotic pressure). The experimental arrangements employed and the preliminary results obtained will be described.

* This work was assisted by a contract with the Office of Naval Research.
[1] J. G. Daunt, R. E. Probst, H. L. Johnston, L. T. Aldrich and A. O. Nier, Phys. Rev. **72**, 502 (1947).
[2] J. G. Daunt, R. E. Probst, and H. L. Johnston, J. Chem. Phys. **15**, 759 (1947).

S3. Countercurrent Gaseous Exchange Method for the Enrichment of Isotopes. R. B. BERNSTEIN AND T. I.

TAYLOR, *Columbia University.*—A method is described for the enrichment of isotopes by countercurrent gaseous exchange in a thermal diffusion column. The theory is derived for two cases of interest: diffusion limited and reaction-rate limited. Solutions of the equations are presented for the over-all separation at the steady state as a function of the following: single stage enrichment factor α; diffusion constant D or exchange rate constant k; length of column Z; and the convective flow L which in turn depends upon pressure, temperature, column dimensions, etc. The results may be expressed in the usual form $S=\alpha^N$. For the diffusion limited case $N=4\pi D\bar{c}Z/L$ and for the reaction rate limited case $N=kA_h\bar{c}Z/L$ where $\bar{c}$ = moles of gas per cc and A_h = cross-sectional area of hot gas stream. The latter simplifies to the result that the number of theoretical plates per unit length is given by $N/Z=k/v$ where v is the convective velocity. Experiments are described in which C^{13} was concentrated by the exchange reaction $C^{12}O_2+C^{13}O=C^{13}O_2+C^{12}O$. The observed dependence of the over-all separation upon the operational variables is consistent with the theory.

S4. Thermal Diffusion with Neon. F. K. ELDER, JR.,* *Yale University.*—A two-stage, Clusius-Dickel hot wire thermal diffusion apparatus of six-meter length was designed and constructed for separation of neon isotopes. Discontinuous operation for a period of eight days produced 300 cc enriched in the heavier isotopes, and 1300 cc enriched in the lighter isotope (both volumes at two-thirds of an atmosphere pressure). Three liters (NTP) of spectroscopically pure neon were used, having as the initial relative concentration of neon 20, 21, and 22:90.4 percent, 0.30 percent, and 9.27 percent, respectively. The final concentrations, given in the same order, were 56.4 percent, 0.80 percent, and 42.8 percent, at the heavy end; and 99.3 percent, 0.15 percent, and 0.51 percent, at the light end. The separation factor for neon 22:20 reached its maximum value of about 150 in 72 hours and maintained that value until the apparatus was shut down 115 hours later. The results on neon 21 concentration are somewhat inexact, because of the small quantities of this isotope involved, but the indicated equilibrium separation factor for neon 21:20 is a little over nine, reached in approximately the same time as that for neon 22:20.

* Now at the University of Pennsylvania.

S5. Theory of Isotope Separation in Geological Processes. W. H. FURRY, *Harvard University.*—Isotope separation may occur in geological processes either because of differences in diffusion rates or because of differences in chemical equilibria. Both the fraction of the material affected and the changes in concentration produced must be small compared with results obtained in artificial processes of separation because of the absence of counterflow. Appreciable effects may be produced, however, on account of the very long times involved. Measurement of these effects could perhaps be useful as one source of evidence about the conditions which prevailed during certain geological processes. In some idealized cases the differential equations describing such effects possess simple solutions which show the dependence of the separation on the time and on quantities such as diffusion coefficient and rate of flow.

S6. Critical Fields of Superconducting Vanadium. ROBERT T. WEBBER AND J. M. REYNOLDS, *Yale University.**—The transitions into superconductivity and the critical fields have been investigated in two spheroidal globules of vanadium about $\frac{1}{8}''$ in diameter and of about 99.7 percent purity. An induction method was used in which a weak alternating magnetic field was superimposed on steady magnetic fields of intensities up to 9000 gauss. The e.m.f, generated in a small secondary coil wound around the specimens was amplified and continuously recorded. The transitions in the absences of the constant field were very broad, extending from approximately 4.2 to 3.5°K, and slightly lower than those reported by Meissner and Westerhoff.[1] The steady magnetic fields necessary to quench the superconductivity were very intense, increasing by about 5000 gauss per degree K below the beginning of the transition. The amount of shielding in the secondary agreed approximately with calculations, although hysteresis effects were observed and a preliminary measurement of the field distortion using a fine bismuth strip indicated little Meissner effect and some frozen in moment. A check on the alternating field induction method using a small sample of tin gave results in excellent agreement with the results of de Haas and Engelkes.[2]

* Assisted by the Office of Naval Research.

[1] W. Meissner and H. Westerhoff, Zeits. f. Physik **87**, 206 (1933).

[2] W. J. de Haas and A. D. Engelkes, Physica **4**, 325 (1937).

SATURDAY MORNING AT 11:00

Pupin 301

(L. A. DUBRIDGE presiding)

Invited Papers

S7. Recent Developments in Quantum Electrodynamics. JULIAN SCHWINGER, *Harvard University.* (45 min.)

S8. Visible Radiation from Accelerated Electrons in 70-Mev Synchrotrons. H. C. POLLOCK, F. R. ELDER, AND R. V. LANGMUIR, *General Electric Company.* (15 min.)

SATURDAY MORNING AT 10:00

McMillin Theatre

(J. R. DUNNING presiding)

Mainly Neutron Physics

U1. The Al(αn) and Si(dn) Neutron Spectra. R. A. PECK, JR., *Yale University.**—A thin silicon target has been bombarded with 3.7 Mev deuterons, and a thick aluminum target with 7.6 Mev alpha-particles. In each case, the neutrons evolved have been studied and their energy distribution plotted following a conventional microphotographic method. The silicon spectrum was partly analyzable into the constituent isotopic reactions (target nuclei of masses 28, 29, 30). It has yielded mass values for P^{29} and P^{31}, and two low lying excitation levels of P^{30}. The aluminum reaction, involving a single isotope target element, has provided a value for the mass of P^{30}.

* This work was assisted by the Office of Naval Research.

U2. Neutron Diffusion in Hydrogenous Media.* C. W. TITTLE† AND CLARK GOODMAN, *Massachusetts Institute of Technology.*—Knowledge of the spatial distribution of neutrons in hydrogenous media is important in the design of radiation shields. Heterogeneous mixtures of Bi+H_2O, Pb+H_2O and Fe+H_2O have been studied by Munn and Pontecorvo.[1] Before extending this work, a comparison has been made between homogeneous and heterogeneous mixtures of carbon, hydrogen, and oxygen having the same C:H:O ratios per unit volume. Source: 150 mg Ra$-\alpha-$Be; homogeneous mixture: furfural, $C_5H_4O_2$; heterogeneous mixture: Acheson graphite and water. Intensities of thermal and indium resonance neutrons were measured to distances of 54 cm and 30 cm, respectively, from the source using In and Cd$-$In$-$Cd foils. A checkerboard lattice consisting of rods of graphite (1.92 cm$\times$1.92 cm) spaced 0.77 cm apart in water, when corrected for minor differences in atomic concentrations, gave distributions equivalent to the homogeneous mixture beyond 12–20 cm (12, indium resonance; 20, thermal). Slabs of graphite 1.92 cm thick spaced 1.83 cm under equivalent conditions gave the same distributions beyond 14–24 cm. At 4 cm the intensity ratios for thermal neutrons were 1.00:0.91:0.81:furfural:checkerboard:slab.

* This work was supported in part by the Office of Naval Research.
† Gulf Oil Corporation Fellow in Physics.
[1] Munn and Pontecorvo, Can. J. Research **25A**, 157–167 (1947).

U3. Transmission of Monoenergetic Slow Neutrons Through Solid Solutions and Mechanical Mixtures of TiC and WC. S. S. SIDHU, *Argonne National Laboratory.*—TiC and WC form continuous substitutional solid solutions at least up to 25 percent TiC+75 percent WC by weight when heated to 4000°F, TiC being the solvent and WC the solute. Total neutron scattering cross sections of a series of finely powdered solid solutions and corresponding mechanical mixtures of the two carbides were determined as a function of the mole percent of WC from the measured transmission of monoenergetic neutrons with energies 0.08138, 0.03479, 0.02056, and 0.01526 ev or wave-lengths $\lambda=1.004$A, $\lambda=1.536$A, $\lambda=1.998$A, and $\lambda=2.319$A, respectively. The cross sections of both the solutions and the mixtures increase with increasing mole percent of WC. For mixtures they are the same as the additive cross sections, each constituent scattering independently of the other. They are analogous to x-ray scattering from the mixtures in which each constituent gives its own diffraction pattern, and the patterns of the two constituents are superimposed. The neutron cross sections of solid solutions are lower than those of the mixtures at low percentages of WC but increase rapidly with the concentration of the solute molecules. They appear to be sensitive both to the structure of the solvent and the concentration of the substituting atoms.

U4. Laue Photography of Neutron Diffraction. C. G. SHULL, M. C. MARNEY AND E. O. WOLLAN, *Clinton National Laboratory.*—Using a collimated beam of thermal neutrons from the Clinton pile, it has been possible to photograph the Laue pattern produced by neutron diffraction in single crystals. The photography was accomplished with x-ray film placed next to a sheet of indium foil. Neutron capture in the indium foil produced beta-particle emission with resultant blackening of the x-ray film at the Laue spot positions. Typical Laue photographs will be shown and the sensitivity of the present method will be compared to the usual x-ray technique.

U5. Slow Neutron Velocity Spectrometer Studies of Fe, Ni, and Cu. L. J. RAINWATER, W. W. HAVENS, JR. AND C. S. WU, *Columbia University.*—According to a recent theory of Feshbach, Peaslee, and Weisskopf[1] the slow neutron scattering cross section of elements should be $\sigma_{scatt}\sim 4\pi R^2$ when the neutron energy is not near (relative to the level spacing) that of a resonance. This was shown to apply for most elements[1] with the particular exceptions of Fe, Ni, and Cu which have unusually large scattering cross section in the thermal region. On the basis of this theory[1] large scattering cross sections are observed for energies just above resonance energies, so there should be virtual levels spaced near to zero energy (relative to the level spacing). The scattering cross section should then decrease with neutron energy in a well defined manner related to the level spacing and the position of the virtual level. For Fe the cross section below 300 ev is well matched by $\sigma=(11.0+0.35E^{-\frac{1}{2}})$ neglecting low energy crystal interference effects. Below 60 ev the Ni cross section is well matched by $\sigma=(17.0+0.77E^{-\frac{1}{2}})$ and a resonance is observed near 100 ev. Below 20 ev the Cu cross section is well matched by $\sigma=(7.8+0.54E^{-\frac{1}{2}})$. The cross sections decrease at higher energies.

[1] Feshbach, Peaslee, Weisskopf, Phys. Rev. **71**, 145 (1947).

U6. Slow Neutron Velocity Spectrometer Studies: Crystal Interference and Molecular Binding Effects at Low Energies. W. W. HAVENS, JR., L. J. RAINWATER, AND C. S. WU, *Columbia University.*—The slow neutron cross section of H in paraffin changes from about (20.6 ± 1) above 1 ev to $\sim$76 at 0.005 ev showing the effective increase in the (n, p) reduced mass caused by chemical binding. Below 0.05 ev the results are in good agreement with Bethe's theoretical curve.[1] The cross section of D_2O increases from 10.5 above 1 ev to $\sim$20 at 0.005 ev caused by reduced mass binding effects. The cross section is in fair agreement with $(10+0.72E^{-\frac{1}{2}})$ over the region studied. Optical crystals of quartz and calcite were studied to determine the degree of transparency at low energies, the value of the additive cross section at higher energies, and the shape of the curves in the transition region. The SiO_2 cross section is nearly constant at 9.0 above 0.57 ev and at 1.25 below 0.01 ev with a mid-value of 5.0 at 0.1 ev. Similarly, the $CaCO_3$ cross section is nearly constant at 19.8 above 0.9 ev and at 3.5 below 0.009 ev with a mid-value of 11 at 0.08 ev. Other results will be shown.

[1] Bethe, Rev. Mod. Phys. **59**, 127 (1937).

U7. Slow Neutron Cross Sections of Oxygen, Nitrogen, Argon, and the Proton in Methane, Ethane, *n*-Butane, Ethylene, and 1,3 Butadiene, as Measured with a Neutron Beam Spectrometer.[1] EDWARD MELKONIAN, *Columbia University.*—The samples were in the gaseous phase. The theoretical interpretation of the scattering of neutrons by O_2 molecules must include magnetic scattering.[2] The free oxygen atom cross section was found to be 3.68×10^{-24} cm^2. In the thermal region, the N_2 and A cross sections can be represented by:

N_2: $[9.60+0.48E^{-\frac{1}{2}}]\times10^{-24}$ cm^2 per atom
A: $[0.640+0.123E^{-\frac{1}{2}}]\times10^{-24}$ cm^2 per atom

where E is the neutron energy in ev. The proton cross section between 2.5 and 15 ev neutron energy was found to be essentially constant, and the average of all results gave as the free proton cross section $19.96\pm0.2\times10^{-24}$ cm^2 per proton. Above 15 ev the resolution width used caused an appreciable effect by fast neutrons. Below 2.5 ev chemical binding effects became important, and all the curves differed, showing the effect of binding in different molecules.

[1] Rainwater, Havens, Wu, and Dunning, Phys. Rev. **71**, 65 (1947).
[2] Halpern, Phys. Rev. **72**, 746 (1947).

U8. Thermal Neutron Absorption Cross Sections of Separated Isotopes. H. POMERANCE AND J. I. HOOVER, *Clinton National Laboratory.*—The thermal neutron absorption cross sections of small samples of enriched isotopes have been measured in the Clinton pile oscillator. Some of the values (in barns) to be reported are as follows:

Ag^{107}	Ag^{109}	Ni^{58}	Ni^{60}	Fe^{54}	Fe^{58}	Fe^{57}
30.0	83.7	4.3	2.7	2.1	3.1	0.5

Normal isotopic mixtures of these metals were run in conjunction with the measurements on the separated isotopes as a check on the consistency of the results. Preliminary data on Mo indicate that about 80 percent of its cross section is due to Mo^{96}. The values given above were obtained by comparing the unknown sample with a gold sample, for which a σ_a of 95 barns was assumed. Corrections for the isotopic impurities were made where possible. The separated isotopes were supplied by the *Y*-12 Isotope Development Department under the supervision of C. P. Keim. We wish to acknowledge our indebtedness to this group.

U9. Cross Section Measurements Using Fast Continuous Energy Neutrons. V. L. PARSEGIAN,* L. V. TITONE, AND C. W. VAN DER MERWE, *New York University.*—The total cross section $\sigma_t(E)$ of a scatterer for fast neutrons is usually determined by transmission measurements, using a series of "monoenergetic" neutron beams. In the absence of suitable neutron sources a method is proposed by which $\sigma_t(E)$ may be determined using continuous energy neutrons, such as from Ra–Be mixtures. It has been shown by Baldinger, Huber and Staub that the energy distribution $S(E)$ of a neutron beam may be determined by measuring the number-energy distribution $H(E)$ of nuclear recoils occurring in an ionization chamber. According to the proposed method for determining $\sigma_t(E)$, it is shown that if the recoil distribution is determined with and without an intercepting scatterer, the relation $\exp(-n\sigma_t(E)x) = [dH(E)/dE]/[dH_0(E)/dE]$ holds, in which $dH(E)/dE$ and $dH_0(E)/dE$ are the slopes of the recoil distributions at neutron energy E, for the distributions obtained with and without the scatterer, respectively (n is the atoms per cm^3 and x the length of scatterer). $\sigma_t(E)$ may then be obtained from the ratio of slopes of the two distributions over the entire range of the neutron source. The method offers means for determining other than total cross sections, including possibly resonance effects, and may prove useful in connection with neutrons obtained from atomic piles.

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U10. Angular Dependence of Coincidences Between Fission Neutrons. S. DEBENEDETTI, J. E. FRANCIS, JR., W. M. PRESTON, AND T. W. BONNER, *Clinton National Laboratory.*—Coincidences between fission neutrons were measured at angular separations of 30°, 60°, 90°, 135°, and 180°. The source was a sample of U^{235} irradiated in a beam from the Clinton Pile. The neutrons were detected with two proportional counters containing hydrogeneous material in the form of 20 polythene films perpendicular to the wires. The counters were located in a plane perpendicular to the beam and were connected to a coincidence circuit of 3×10^{-7} sec. resolving time. The spurious coincidences measured with a PoBe source of the same strength as our fission sample, consisted of random coincidences (considerably more numerous than the desired effect) and of coincidences arising when the same neutron produced a recoil in both counters (important only at 30°, where they about equaled in number the true coincidences). After subtraction of the spurious coincidences the final results are affected by a statistical error of about 10 percent. The number of coincidences is constant from 30° to 90° and increases by a factor 2 from 90° to 180°. Using the hypothe-

sis of neutron emission from fragments in motion, this result shows that when more than one neutron per fission is emitted both fragments contribute to neutron emission.

U11. Angular Correlation of γ-Rays. EDWARD L. BRADY AND MARTIN DEUTSCH, *Massachusetts Institute of Technology.*—The study of the angular correlation of successive γ-rays[1] has been continued with improved equipment which will be described. The results for Co^{60} gave the following values for ϵ_θ, defined as the true coincidence counting rate at the angle θ minus the true coincidence rate at $\theta=90°$ divided by the rate at 90°: $\epsilon_{180}=0.216\pm0.025$; $\epsilon_{135}=0.075\pm0.026$; $\epsilon_{120}=0.048\pm0.025$; $\epsilon_{60}=0.002\pm0.022$. The fact that the lifetime of the intermediate state is short compared to the precession period of the nucleus in the field of its own electrons was established by the observation that the anisotropy is not affected within the statistical error by the application of a magnetic field of about 10,000 gauss. This work was supported in part by the Office of Naval Research.

[1] E. L. Brady and M. Deutsch, Phys. Rev. **72**, 870 (1947).

U12. Relative Yields of Some X-Ray Induced Nuclear Reactions. G. FRIEDLANDER AND M. L. PERLMAN, *General Electric Company.*—The yields of a number of nuclear reactions induced by x-rays from the 100 Mev betatron have been compared by measurement of the radioactivities of product nuclei. In addition to the (γ, n) reactions previously investigated,[1] (γ, p) reactions on Si^{30}, Ni^{62}, Mo^{98}, and Ru^{102} and $(\gamma, 2n)$ reactions on F^{19} and Cu^{63} have now been studied. At 100 Mev maximum energy, the values of the four (γ, p) yields show a spread of about 50 percent and are comparable to those of the (γ, n) yields among elements below nickel. The abrupt increase observed in the neighborhood of $Z=29$ for (γ, n) yields[1] was not found for the (γ, p) yields. Each of the two $(\gamma, 2n)$ reactions studied was found to be approximately one tenth as probable at 100 Mev maximum energy as the (γ, n) reaction on the same nuclide. It is hoped that further results will be available at the time of the meeting.

[1] M. L. Perlman and G. Friedlander, Phys. Rev. **72**, 15 (1947).

U13. X-Ray Yield Curves for γ-*n* Reactions. G. C. BALDWIN AND G. S. KLAIBER, *General Electric Company.*—Yield curves for the reactions $C^{12}(\gamma, n)C^{11}$ and $Cu^{63}(\gamma, n)Cu^{62}$ have been taken with x-rays up to 100 Mev. The induced radioactivity at each energy is plotted per unit x-ray intensity as measured by an *r*-meter thimble jacketed by $\frac{1}{8}''$ of Pb. Both yield curves are similar to the photo-fission yield curves,[1] the x-ray yield increasing to a maximum and then slowly decreasing as the x-ray energy is increased. With simple assumptions regarding the generation of ionizing secondaries in the Pb walls of the monitor and assumption of a constant intensity x-ray spectrum, these curves can be analyzed. The relative cross section is found to have a maximum at approximately 22 Mev for Cu^{62} and 30 Mev for C^{11}, decreasing to negligible values at high quantum energies. This decrease in cross section can be attributed to competition from multiple disintegrations. These reactions provide detectors sensitive only to part of the x-ray spectrum. Absorption curves have been taken in Pb using uranium photo-fission and in Cu and Pb using the $Cu^{63}(\gamma, n)Cu^{62}$ reaction as detectors. The resulting absorption coefficients compare favorably with theoretical values.

[1] G. C. Baldwin and G. S. Klaiber, Phys. Rev. **71**, 3 (1947).

SATURDAY AFTERNOON AT 2:00

Havemeyer 309

(R. M. BOWIE presiding)

Invited Papers of the Division of Electron Physics

V1. Electrical Phenomena in Gases at Microwave Frequencies. W. P. ALLIS, *Massachusetts Institute of Technology.* (40 min.)

V2. Some Discharge Phenomena in Fluorescent Lamps. E. G. F. ARNOTT, *Westinghouse Electric Corporation.* (25 min.)

V3. Cathode Phenomena in the Electric Arc. J. D. COBINE AND C. GALLAGHER, *General Electric Company.* (25 min.)

V4. Resolution in Electron Microscopes. JAMES HILLIER, *RCA Laboratories.* (30 min.)

SATURDAY AFTERNOON AT 2:15

Pupin 428

(C. H. TOWNES presiding)

X1. Mass Spectrometric Study of Some Deuterated Hydrocarbons. RICHARD E. HONIG, *Research and Development Department, Socony-Vacuum Laboratories.*—If deuterated hydrocarbons are to be used as stable tracers in studying chemical reactions, preliminary investigations of their behavior in the mass spectrometer are of interest. The

following compounds were synthesized from D_2O (atom percent D>99) and studied: CH_3D, CD_4, C_2D_2, C_2H_5D, $CH_3CH_2CH_2D$, and CH_3CHDCH_3. Mass spectra, obtained with 50-volt electrons, of CD_4 and C_2D_2 resemble closely those of CH_4 and C_2H_2, whereas the singly deuterated compounds show significant deviations from the regular patterns which may be explained by differences in bond strengths. The deuterium position in the two propane isomers is accurately reflected by their respective spectra. Intensities/pressure (sensitivities) of the parent ions are the same within the experimental uncertainty for deuterated and regular hydrocarbons. A 13 percent difference observed for $CH_3CH_2CH_2D$ and C_3H_8 appears to be caused by impurities contained in the former. Ionization potentials, measured reproducibly to ± 0.02 volt, could not distinguish between deuterated and regular compounds. Only for CD_4 and CH_4 was a significant difference of 0.17 ± 0.04 volt observed, which may be explained by shifts in the zero-point energies of the two molecules.

X2. Specificity of Interaction Between Pairs of Identical Large Molecules. H. JEHLE, *University of Pennsylvania and Institute for Advanced Study.*—In self-duplication of chromosomes the original chromosome selects from the surrounding medium molecules which happen to be identical with the constituent molecules of the genes. Synapsis of homologous chromosomes is a similar process. Investigation of the thermally excited internal vibrations of these fairly rigid molecules shows many of them to belong to the domain of non-linear mechanics. Consider a pair of corresponding modes of a pair of identical molecules. While they accidentally approach each other by Brownian motion, the vibrations of the pair, which formerly had two degrees of freedom, lock in synchronism. The corresponding loss of a degree of freedom per pair of modes results in a surplus energy kT which will be dissipated into the medium. Conversely, to separate the pair we need kT per each synchronized pair of modes. The energy (about kT) of relative motion of the two molecules and that of non-synchronized modes are an insufficient reservoir to get the pair apart out of this mutual trap. This argument for capture usually fails if one of the molecules has been slightly altered, since such an alteration usually changes the entire frequency spectrum. It also fails for the same reason if a pair of identical molecules is confronted with an approaching third.

X3. Use of Mechanical Synthesizer to Determine Characteristics of Non-Dissipative Electric Wave-Filters. S. LEROY BROWN AND JAMES M. SHARP, *University of Texas.**—The mechanical harmonic synthesizer may be used to plot polynomials after they have been reduced to an equation in harmonic functions of θ by a substitution of the form $x = R\cos\theta$ where R is an arbitrary modulus. Since, in any electrical network containing both L and C components, the expression for the reactance reduces to the ratio of two polynomials in ω ($2\pi \times$frequency), the synthesizer may be utilized to determine, indirectly, the variation of reactance with frequency. The method employed is to plot with the synthesizer the first polynomial, the numerator, and then the second, the denominator of the expression for the reactance. The numerical value of the reactance in ohms is then the ratio of respective ordinates read from the two curves corresponding to any particular value ω (plotted as abscissa). This method is extended to plotting the important quantity in filter circuits $X_1/-4X_2$ from which the cut-off frequencies, attenuation, phase shift, and iterative impedance are determined.

* Assisted by Office of Naval Research.

X4. Work, Heat, and Temperature Concepts in Thermodynamics and an Examination of the Temperature Scale. J. L. FINCK, *The J. L. Finck Laboratories.*—In this paper the concepts of work, heat, and temperature are examined from the standpoint of a complete equation* for the internal energy of a system. In an incomplete system energy necessarily remains with the system, which results in the inefficiency of a process. This inefficiency is, of course, appreciable for processes taking place at a finite speed, but is not necessarily eliminated by means of a quasi-static process. The Kelvin temperature scale is shown to be based on an incomplete equation for the internal energy and therefore offers certain difficulties. A temperature scale based on a complete equation is shown to have advantages over the Kelvin scale, and it is further shown that the temperature of absolute zero as based on a complete equation is lower than that on the Kelvin scale.

* Bull. Am. Phys. Soc. **22**, 28 (1947), p. 16, T1.

X5. Measurement of Rocket Flame Velocity by Doppler Shift. F. P. BUNDY, *General Electric Company.*—Rocket flame velocity is usually deduced from measurements of the thrust force and mass flow rate made on the rocket motor. In response to a need for an independent absolute measurement of the flame velocity, a method has been developed which is based on the Doppler shift of the sodium *D*-line radiation from the flame. The small shift of wave-length is measured from interference patterns formed by a Fabry-Perot interferometer. Because the spectral line width is greater than the Doppler shift it is necessary to photograph separate interference patterns using upstream and downstream light and then compare the positions of the fringes. The accuracy of the method with the present apparatus is within ± 10 percent. With the improved apparatus which is being set up it is expected to bring the accuracy to within less than ± 5 percent. Some of the optical and mechanical problems encountered in the development will be discussed. A few interesting spectroscopic effects produced by rocket flames will be presented.

X6. A Simple Temperature Controller. J. C. MOUZON, *The Brown Instrument Company.*—A simple temperature controller has been developed which permits thermostating of equipment to closer limits than is possible with ordinary on-off control. The sensitive element is a resistance thermometer which is employed in a 60-cycle a.c. bridge. The output of the bridge is amplified by one-half of a dual triode and is fed to the grid of a thyratron. The other half of the dual triode is used as a rectifier to supply d.c. to the amplifier stage. The plate circuit of the thyratron includes the heater load. A.c. power is supplied to the thyratron and

heater circuit. The use of a.c. on the bridge and thyratron makes the control essentially independent of line voltage. By shunting the heater load with a condenser or by using a parallel resistance and capacity in the cathode of the thyratron it is possible to obtain proportional action in which the power supplied to the heater is a function of the departure of the temperature from the desired value. This action minimizes the cycling that accompanies on-off control.

X7. Scattering and Transmission Cross Sections of Circular Disks and Apertures for Sound and Electromagnetic Waves.* R. D. SPENCE, *Yale University.*—This note reports the results of calculations on the scattering cross section of a circular disk for normally incident sound waves and on the transmission cross section of circular apertures for sound and electromagnetic waves. The calculations were made by separating the wave equations in oblate spheroidal coordinates. Numerical results have been obtained in the range

$$0<\frac{2\pi}{\lambda}a<5,$$

where a is the radius of the disk or aperture.

* Now at Michigan State College.

X8. The Development of a Combustion Wave in a Flowing Gas.[1] R. J. DERY,[2] *Bureau of Mines.*—A flame front is propagated in a flowing gas with a velocity which is the resultant of the flame-propagation velocity in the direction of the normal to the flame front and the velocity of the unburned gas. The case of a combustion wave in a gas in Poiseuille flow in a cylindrical tube has been investigated theoretically for an ideal system with constant burning velocity, constant volume, and null lateral expansion of stream tubes. The equation of motion of points on the flame surface in an axial plane relative to a point moving with the velocity v_m of the gas on the axis of the cylindrical jet is then $\vec{u}=a\vec{n}-(r^2/R^2)v_m$, where $\vec{n}$ is the outer normal to the flame surface and R the radius of the jet. Schlieren photographs of the initial stages of spark-ignited flames in gas issuing from a tube are in agreement with the theory.

[1] Published by permission of the Director, Bureau of Mines, U. S. Department of the Interior.
[2] Physical Chemist, Physical Chemistry and Physics Section, Explosives Division, Central Experiment Station, Bureau of Mines, Pittsburgh, Pennsylvania.

X9. The Approximate Small Signal Theory of Electron Beam Wave Interaction in a Wave Guide with a Filament Beam. PHILIP PARZEN, *Federal Telecommunication Laboratories.*—The small signal electron beam wave interaction in a wave guide is characterized by an axial propagation constant h, which may be obtained from the constants, h_n, for the cold guide by considering the beam as a source of forced vibrations, periodic in space, of the fields, which are expanded in the normal modes of the cold guide. For a filament beam, h is given by

$$1=\frac{(k^2-h^2)}{(\beta-h)^2}R\sum_n\frac{B_n}{h_n^2-h^2},$$

where $k=2\pi/\lambda$, $\beta=\omega/v_0$, v_0 is d.c. velocity of beam, R is 10^5I_0 (amps)$/V_0^{\frac{1}{2}}$ (volts) and $B_n=|E_n|^2/N_n$, where E_n is the longitudinal electric field of the nth cold mode at the beam and $N_n=\int|E_n|^2dA$ over the guide cross section.

X10. Further Report on High Pressure Experiments on Supersonic Propagation. GERALD J. HOLTON, *Harvard University.*—The experimental arrangement and some of the results for measurements of sound velocity and attenuation in liquids at high pressures have been presented recently.* Further data and a summary of the theoretical conclusions are now given. Included are discussions of specific heats, relaxation times, and molecular association in liquids like water; for instance, it can be shown that the absorption at 15 mc/sec. approaches the classical value at pressures from a few hundred to several thousand atmospheres, depending on the temperature.

* A. P. S. Meeting, November 1, 1947.

SATURDAY AFTERNOON AT 2:15

Horace Mann Auditorium

(LYLE BORST presiding)

Y1. Disintegration of Isomers of Ba^{133}. FU-CHUM YU AND J. D. KURBOTOV, *The Ohio State University.*—By the activation of barium with slow neutrons a radioactive isotope of barium of half-life of over 20 years has been obtained. After sufficient time is allowed for the 12-day Ba^{131} to disintegrate, long-life barium was found to emit gamma-rays of energy of 310 kev, conversion electrons, and x-rays. Independently by activation of cesium with deuterons followed by chemical separation of barium, radiations emitted by two isomers of Ba^{133} (1) of the previously known half-life of 38.8 hours and (2) of a long life have been studied. From the evidence of the accumulation of gamma-ray intensity of a long-life isomer during the disintegration of the 38.8-hour isomer, the genetic relationship between these two isomers was established. A scheme of disintegration of the isomers of Ba^{133} will be proposed.

Y2. Radiations from Antimony (124).* M. V. SCHERB AND C. E. MANDEVILLE, *Bartol Research Foundation.*—The characteristic radiations of Sb^{124} have been re-investigated.[1,2] The hard gamma-ray was found to have an energy of 1.67 Mev as measured by coincidence absorption. This value agrees well with the many earlier determinations. The beta-rays, measured by aluminum absorption, had a

maximum energy of 1.62 Mev, agreeing fairly well with earlier absorption measurements of the Indiana group,[1] but differing from subsequent spectrometric data by as much as 0.83 Mev. The genuine beta-gamma coincidence rate decreased from an extrapolated value of 0.92×10^{-3} coincidence per beta-ray at zero absorber thickness to 0.38×10^{-3} coincidence per beta-ray at 0.11 g/cm² in aluminum. The inner beta-ray group then has an end point at about 0.5 Mev. A gamma-gamma coincidence rate of $(0.59\pm0.03)\times10^{-3}$ coincidence per gamma-ray was also observed.

* Assisted by the Office of Naval Research.
[1] Mitchell, Langer, and McDaniel, Phys. Rev. **57**, 1107 (1940).
[2] Meyerhof and Scharff-Goldhaber, Phys. Rev. **72**, 273 (1947).

Y3. Beta- and Gamma-Radiations from Antimony.* BERNARD D. KERN, DANIEL J. ZAFFARANO, AND ALLAN C. G. MITCHELL, *Indiana University.*—A source of antimony obtained from the Oak Ridge pile was investigated, with respect to its beta- and gamma-rays, by the use of a thin lens magnetic spectrometer. Gamma-ray energies of the 60-day Sb^{124} were determined from photoelectric lines produced with a thin lead radiator and also from Compton electrons produced in copper. The energies of the strongest lines are 0.603 and 1.708 mv. Three weaker lines have energies 0.650, 0.714, and 2.064 mv. The beta-ray spectrum was measured using a source of surface density 5.5 mg/cm² on a backing of 1 mg/cm². The spectrum is complex, and a Fermi plot of the data gives groups with the following end points: 2.32, 1.58, 0.98, 0.63, and 0.47 mv. An internal conversion line was found at 0.571 mv, corresponding to the gamma-ray of energy 0.603 mv. A measurement of the gamma-rays of Sb^{122} (2.7 days), taken before the source was aged, gives a gamma-ray of energy 0.568 mv.

* Supported by the Office of Naval Research.

Y4. Beta- and Gamma-Radiation of Antimony.* C. SHARP COOK AND LAWRENCE M. LANGER, *Indiana University.*—Measurements on the beta- and gamma-rays emitted by antimony bombarded by slow neutrons at Oak Ridge have been made with a high resolution, 40-cm radius of curvature, shaped field magnetic spectrometer.[1] The beta-spectrum of 60-day Sb^{124} was determined after all 2.8-day Sb^{122} had decayed and after chemical separation. A source of 1 mg/cm² plated onto a 0.010″ graphite backing was used. The counter window had a low energy cut-off of 2.0 kev. The spectrum is complex and by means of the Fermi plot may be resolved into five groups having maximum energies at 2.37, 1.50, 0.98, 0.68, and 0.50 Mev. An internal conversion line was observed at $H\rho=1050$ gauss-cm, corresponding to a gamma-ray energy of 0.121 Mev. Compton and photoelectrons ejected from a Pb radiator yield lines corresponding to gamma-rays of 2.14, 1.708, and 0.608 Mev. Additional weak lines were observed, which, if caused by K electrons ejected by Sb gamma-rays, correspond to gamma-ray energies of 0.732 Mev and 0.654 Mev. Runs, taken when the source was fresh, yield K and L lines corresponding to a gamma-ray of Sb^{122} of 0.568 Mev.

* This research was supported by the Frederick Gardner Cottrell Fund of the Research Corporation and the Office of Naval Research.
[1] L. M. Langer and C. S. Cook, Rev. Sci. Inst., in press.

Y5. Coincidence Measurements in Sb^{124}. E. T. JURNEY AND ALLAN C. G. MITCHELL, *Indiana University.**—The disintegration of Sb^{124} has been re-investigated,[1,2] using coincidence counting methods. The beta-ray absorption in aluminum was measured, using a single counter with a thin window, and the curves analyzed by the method of Bleuler and Zünti.[3] Two intense groups were found with end points at 2.24 and 0.51 mv. Beta-gamma and gamma-gamma coincidences were measured. When the number of beta-gamma coincidences per beta-ray is plotted against absorber thickness, the curve is practically flat from the highest absorbers used up to a thickness of 168 g/cm², corresponding to the energy of 0.47 mv, where a sharp rise sets in, indicating the presence of a low energy group of electrons. The high energy portion is being investigated further for evidence of additional groups.

* Supported by the Office of Naval Research.
[1] A. C. G. Mitchell, L. M. Langer, and P. W. McDaniel, Phys. Rev. **57**, 1107 (1940).
[2] W. E. Meyerhof and G. Scharff-Goldhaber, Phys. Rev. **72**, 273 (1947).
[3] E. Bleuler and W. Zünti, Helv. Phys. Acta **19**, 375 (1946).

Y6. Absorption Curve of Be^{10} Beta-Rays. WILLIAM E. STEPHENS AND A. M. BOTTOMS, *University of Pennsylvania.*—The aluminum absorption curve of the beta-rays from beryllium[10] [1] has been measured. The results are in agreement with those of McMillan[2] and indicate an apparent end point between 185 and 190 mg/cm² of aluminum. Attempts are being made to reduce the tail (presumably bremsstrahlung) by the use of beryllium holders and absorbers.

[1] Beryllium target fragments supplied by Professor A. L. Hughes and Professor F. N. D. Kurie of Washington University.
[2] E. M. McMillan, Phys. Rev. **72**, 591 (1947).

Y7. The C^{14} Beta-Ray Spectrum. MARGARET N. LEWIS AND MIRIAM PAUL, *University of Pennsylvania.*—Further studies of the C^{14} beta-ray spectrum[1] with a permanent magnet spectrograph have been made. The apparent end point is 152 ± 5 kev. Scattering has been reduced by use of a thin source and support. The energy sensitivity calibration of the film in the region of the end point was made with the use of the line spectrum of Ra *B*.

[1] W. E. Stephens and Margaret N. Lewis, Phys. Rev. **72**, 526 (1947).

Y8. Positron-Electron Ratios in Cu^{64}. L. CRANBERG AND J. HALPERN, *University of Pennsylvania.*—The work of Backus[1] on Cu^{64}, which gives positron-electron ratios in excess of values predicted by theory at energies below 50 kv, is compared with earlier work of Tyler[2] and Townsend.[3] Although spectral shapes from Tyler's work deviate from straight-line Kurie plots at 350 kv for positrons and 320 kv for electrons, positron-electron ratios agree with theory down to energies of approximately 100 kv. This suggests that source scattering of positives and negatives can be treated symmetrically when spectral shapes are similar. Such a situation no longer holds at energies below 50 kv. When Backus' results are compared with ratios taken at the upper end of the spectrum, the discrepancy from theory is greater than was indicated. The low energy region, however, is particularly sensitive to inelastic scattering effects, which will be discussed in detail.

[1] Backus, Phys. Rev. **68**, 59 (1945).
[2] Tyler, Phys. Rev. **56**, 125 (1939).
[3] Townsend, Proc. Roy. Soc. (London) **A177**, 357 (1941).

Y9. Neutron Induced Activities in Erbium. B. H. KETELLE AND W. C. PEACOCK, *Clinton National Laboratory.*—Two erbium activities were produced in ion-exchange[1] separated erbium, by n, γ reactions and were studied with beta-ray spectrometer and coincidence techniques. (1) A 9.4 ± 0.2 $d\beta^-$ emitter has been found. It emits no gamma-rays and has a beta-ray end point of 0.33 ± 0.01 Mev. (2) A 7.5 ± 0.2 $h\beta^-$ emitter has also been found. It has three alternate modes of β^- decay. 71 ± 5 percent of the betas have an energy of 1.05 ± 0.03 Mev and are followed by two gammas of 0.305 ± 0.010 and 0.113 ± 0.005 Mev in cascade. The 0.113-Mev gamma-ray is highly converted and has a half-life of 2.5 μsec. (see following abstract). 6 ± 1 percent of the betas have an energy of 1.49 ± 0.05 Mev and decay directly to the ground state of Tm. 22 percent of the betas have an energy of 0.67 ± 0.03 Mev and are followed by a 0.805 ± 0.025-Mev gamma. From the disintegration energies it appears that the 7.5-h period should be assigned to Er^{171} and the 9.4-d period to Er^{169}. A Tm activity of 500 ± 100-d was shown to grow from the activated Er samples; this is probably Tm^{171} daughter of 7.5-h Er^{171}.

[1] B. H. Ketelle and G. E. Boyd, J. Am. Chem. Soc. November 1947.

Y10. Short-Lived Isomers in Tm^{169} and Tm^{171}. F. K. MCGOWAN AND S. DEBENEDETTI, *Clinton National Laboratory.*—Using a technique previously described, delayed coincidences were observed with sources of 33-days Yb^{169} (K capture to Tm^{169}).[1] The delayed rays are conversion electrons from a state of around 1 μ-sec. half-life and about 0.2-Mev excitation energy. 30 percent of the immediate pulses are due to x-rays from K capture and the rest to conversion electrons from other γ-rays. This proves that at least in some instances the short-lived isomeric state is preceded by the emission of immediate γ-rays. No delayed coincidences were detected with sources of 9.4-days Er^{169},[2] which leads by β^- decay to the same final nucleus as Yb^{169}. Sources of 7.5-hours Er^{171} (β^- decay to Tm^{171})[2] also give delayed coincidences corresponding to a half-life of 2.5 μ-sec. and 0.1-Mev excitation energy. In this case the number of conversion electrons per disintegration is about 0.4.

[1] W. Bethe, Zeits. f. Naturf. 1, 173 (1946).
[2] See preceding abstract.

Y11. The Beta- and Gamma-Spectra of Ga^{72}.* S. K. HAYNES, *Clinton Laboratories and Vanderbilt University.*—The experimental curves obtained in an investigation of the beta- and gamma-ray spectra of Ga^{72} with a thin lens spectrometer are presented and discussed. Evidence is given for the existence of beta-particle groups with maximum energies of 3.15 Mev, (9.5 to 20 percent) 2.5 Mev, (8 to 18.5 percent) 0.955 Mev, (32 percent) and 0.64 Mev, (40 percent). The photoelectron spectrum indicates gamma-rays of the following energies: 2.51 Mev (26 percent), 2.21 Mev (31.5 percent), 1.87 Mev (7.5 percent), 1.59 Mev (4.5 percent), 1.05 Mev (4.5 percent), 0.84 Mev (100 percent), 0.63 Mev (18.5 percent), and possibly a weak gamma-ray at 1.25 Mev (2 percent). A conversion line appears at 0.68 Mev in the beta-ray spectrum, but no corresponding line can be identified with certainty in the photoelectron spectrum. The conversion coefficient is probably between ten and fifty percent, indicating an isomeric state of considerable duration. A partial decay scheme of Ga^{72} is presented.

* This work was performed under contract with the Atomic Energy Commission.

Y12. Radiations from Mo^{99} and Tc^{99}.* C. E. MANDEVILLE AND M. V. SCHERB, *Bartol Research Foundation.*—The 67-hour activity was induced in Mo_2O_3 irradiated by slow neutrons at the Clinton pile. Separations were made for the removal of calcium, iron, phosphorous, and columbium as possible impurities. The energy of the hard beta-rays of Mo^{99} was measured by aluminum absorption and was found to have an end point at 1.03 Mev. Coincidence measurements indicated that no gamma-rays are coupled with the high energy spectrum. A low energy group of beta-rays is present in Mo^{99}, having a maximum range of 0.057 g/cm^2 in aluminum. This spectrum is coincident with gamma-radiation. The gamma-rays have a maximum energy of 0.71 Mev as measured by coincidence absorption. A small gamma-gamma coincidence rate, 0.085×10^{-3} coincidence per gamma-ray, was detected in Mo^{99}. The electrons of the highly converted gamma-ray of the 6-hour metastable state of Tc^{99}, separated from Mo^{99}, were found to be non-coincident with gamma-radiation. Also, no gamma-gamma coincidences were observed in the technetium fraction. The conversion electrons had a range of 0.022 g/cm^2 in aluminum. A disintegration scheme will be proposed.

* Assisted by the Office of Naval Research.

Y13. The 7-Second Au^{197} Isomer. H. FRAUENFELDER, P. C. GUGELOT,† O. HUBER, H. MEDICUS, P. PREISWERK, P. SCHERRER, AND R. STEFFEN, *Swiss Federal School of Technology.*—The decay of the two isomeric states of Hg^{197},[1] produced by the $Au^{197}(p, n)Hg^{197}$ reaction, has been investigated to study the 7-sec. Au^{197*}.[2] Both decay by electron capture. The 25-h activity excites a 0.3-Mev state of gold, from which a cascade of a 0.165-Mev—and a 0.135-Mev γ-ray leads to the ground state. The 65-h activity excites a level of 0.077-Mev above the ground state. No indication of a genetic relation between both periods was found. Coincidence measurements showed that none of these Au levels had an appreciable lifetime. To determine the radiations of the 7-sec. Au^{197*}, we bombarded gold with $Be+D$ neutrons. The half-life was found to be (7.4 ± 0.3) sec. This excited level decays by a *ca.* 0.250-Mev converted γ-ray, which is followed by a *ca.* 0.07-Mev converted γ-ray. By distilling active mercury we obtained this Au activity and found that *ca.* 4 percent of the decay of 25-h Hg^{197} yields this isomeric state. The measured half-life was (7.4 ± 0.2) sec. Absorption curves of the conversion electrons agreed with those obtained by n, n excitation. A tentative energy-level scheme will be given.

† Now at Princeton University.
[1] G. Friedländer and C. S. Wu, Phys. Rev. 63, 227 (1943).
[2] M. L. Wiedenbeck, Phys. Rev. 68, 1 (1945).

SATURDAY AFTERNOON AT 2:00

Pupin 301

(W. E. LAMB, JR. presiding)

Theoretical Physics

Z1. The Mass-Energy Relation.* W. F. G. SWANN, *Bartol Research Foundation.*—Relativity serves only to predict the relation for those portions of the mass and energy which are dependent upon the velocity. Electromagnetic theory comes near to providing for the rest mass in terms of ordinary electrostatic energy, but with the well known discrepancy amounting to a factor of four-thirds. For uncharged particles, electromagnetic theory does nothing. A hypothesis is developed according to which the whole of the rest mass arises from internal motions of the particles in a form consistent with the required behavior of the particles in respect to the apparent forces which they exert. The line of thought is analogous to that of the whole philosophy which sought to see all potential energy as a manifestation of kinetic energy. It has, moreover, the advantage of unifying the concepts of rest energy and kinetic energy in a form which gives the mass-energy relation a more clear-cut meaning. The development is carried out along classical lines following the general idea that in seeking ultimately to develop consistent quantum theory in relation to these matters it is good to start by seeking consistent classical representation.

* The work constitutes a theoretical contribution to the general nuclear physics program supported at the Bartol Research Foundation by the Office of Naval Research.

Z2. A Simplified Notation in Classical Mechanics. H. C. CORBEN, *Carnegie Institute of Technology.*—In non-relativistic classical mechanics, a dynamical system may be specified by N coordinates q_k and the conjugate momenta p_k, i.e. by a point in $2N$-dimensional phase space $Q_i=\{q_k, p_k\}$. If one defines an orthogonal $2N$-vector $P_i=\{p_k, -q_k\}$ all of the canonical equations for a conservative holonomic system may be written in the form $\dot{Q}_i=\partial H/\partial P_i$. The Poisson and Lagrange brackets of two dynamical variables X, Y become simply $(X, Y)=(\partial X/\partial Q_i)(\partial Y/\partial P_i)$ and $[X, Y]=(\partial Q_i/\partial X)(\partial P_i/\partial Y)$ respectively, and all of the P.B. and L.B. relations are contained in $(Q_i, P_j)=[Q_i, P_j]=\delta_{ij}$. The infinitesimal contact transformation generated by $S(P_i)$ leads to $\delta Q_i=\partial S/\partial P_i$. This simplified notation is easily extended to special relativity theory, where for the motion of a single particle $N=4$. By introducing a metric G_{ij} in phase space it may be further extended to general relativity theory, where the corresponding P.B. relations are $(Q_i, P_j)=G_{ij}$. It then follows that in general the Poisson brackets of two coordinates or of two momenta of a particle do not vanish, being proportional to the antisymmetrical off-diagonal 4×4 tensors of G_{ij}. In the corresponding quantum theory it would be necessary to represent the position of a particle by operators which do not commute.

Z3. On Multiple Excitation of an Elastic System. G. S. BENNETT, *Michigan State College.*—Approximate solutions to the non-linear differential equations are used to evaluate the importance of possible combination frequency resonances where two sinoidal forces are applied to a one degree of freedom elastic system which has a force function expressible as a power series in displacement. It is shown that such resonances exist, but that the maximum amplitudes at resonance are generally much less than the "static" displacement due to one of the exciting forces, and so can be disregarded as a source of trouble in vibration problems. The same method is used and the same general remarks made for the case when the damping function is expressible as a power series in velocity.

Z4. Symmetric Energy-Momentum Tensor of Iwanenko-Sokolow Field. C. KIKUCHI, *Michigan State College.*—The Lagrangian

$$L=\tfrac{1}{2}\{\kappa_1^2\kappa_2^2\varphi_\alpha\varphi_\alpha+\tfrac{1}{2}(\kappa_1^2+\kappa_2^2)F_{\alpha\beta}F_{\alpha\beta}+F_{\alpha\beta,\gamma}F_{\alpha\beta,\gamma}\}$$

which leads to the Iwanenko-Sokolow[1] field equations $(\Box-\kappa_1^2)(\Box-\kappa_2^2)\varphi_\alpha=0$ will be used to indicate how the symmetric energy-momentum tensor can be derived for fields whose Lagrangian depends upon the derivatives of the field quantities. The method due to F. J. Belinfante[2] will be used.

[1] D. Iwanenko and A. Sokolow, J. of Phys. USRR **8**, 54, 358 (1944).
[2] F. J. Belinfante, Physica **6**, 887 (1939).

Z5. First Passage Time Moments for Certain Markoffian Random Functions. A. J. F. SIEGERT, *Northwestern University.*—Let $y(t)$ be a stationary Markoffian random function for which the moment conditions are fulfilled, so that a Fokker-Planck equation is satisfied by the probability density $P(y_0/y, t)$.[1] We define $p(y_0/t', a)dt'$ as the conditional probability that $y(t)$ passes the value $a>y_0$ for the first time between $t'>0$ and $t'+dt'$, provided that $y(0)=y_0$. From the equation

$$P(y_0/y, t)=\int_0^t p(y_0/t', a)P(a/y, t-t')dt'$$

for $y>a>y_0$ and its Laplace transform we then obtain the recursion formula for the moments $t_n(y_0, a)$ of the first passage time:

$$t_n(y_0, a)=2n\int_{y_0}^{a}dz[B(z)W(z)]^{-1}\int_{-\infty}^{z}W(x)t_{n-1}(x, a)dx$$

with $t_0(y_0, a)=1$, where $W(z)=P(y_0/z, \infty)$ and $B(z)$ is defined in the reference p. 331, Eq. (38).

[1] M. C. Wang and G. E. Uhlenbeck, Rev. Mod. Phys. **17**, 323, 331, 332 (1945).

Z6. Observable Effects of the Quantum Fluctuations of the Electromagnetic Field. T. A. WELTON, *Massachusetts Institute of Technology.*—Under the action of the zero-point fluctuations of the electromagnetic field a free charged particle will exhibit forced oscillations about its mean position. The mean square amplitude of this fluctuation in position can be simply calculated in the non-relativistic limit. This fluctuation is too small to be observable in a macroscopic experiment but, for an electron in a hydrogen atom, the fluctuation in position will give rise to a change in the effective potential energy. The alteration will be proportional to the mean square displacement and the Laplacian of the potential energy. It is easily seen that the sign of the change is such as to weaken the effect of the potential energy. In this way, a simple, reasonably quantitative explanation is given of the displacement of the $2S$ level of hydrogen recently observed by Lamb. Similarly, a simple discussion can be given of the higher order corrections to such processes as elastic scattering. The same methods can be used to calculate the fluctuation in direction of a free spin. This effect is closely related to the anomalies in Zeeman and hyperfine splittings observed in recent molecular beam experiments. A discussion will be given of this point.

Z7. On the Method of Virtual Quanta. M. LAX, *Syracuse University* AND H. FESHBACH, *Massachusetts Institute of Technology.*—A quantum analogue of the classical Weizsäcker-Williams method has been derived in which it is shown that, in the Born approximation, the electromagnetic field of a charged particle whose energy is large compared to its rest mass, can be replaced by an equivalent spectrum of transverse and longitudinal photons. The range of applicability is that of the Born approximation and thus may include the case of close impacts involving high energy virtual quanta. In the procedure used, the electromagnetic field generated when the charged particle changes its momentum by ν and its energy by ν_0 is approximated by the Moller formula. The denominator $(\nu^2-\nu_0^2)^2$ insures that the scattered particle comes off in essentially the forward direction for high energy particles. Integration over all directions of the scattered charge and comparison of the charged induced cross section with the photon induced cross section with the approximation $\nu=\nu_0$ yields the desired equivalent photon distribution. Criteria for the general validity of the $W-W$ method may now be given. The inclusion of the longitudinal photon spectrum increases its range of applicability. An extension of this procedure to meson theories permit the derivation of an equivalent meson spectrum of a nucleon.

Z8. The Electromagnetic Level Shift. H. A. BETHE, *Cornell University.*—The shift of the energy levels of a bound electron, due to its interaction with electromagnetic radiation, is calculated relativistically. No numerical result has yet been obtained, but it has been shown that the result is finite, and is of the same order of magnitude as that of the previous non-relativistic theory. To obtain this result, it is necessary to subtract from the self-energy of the bound electron, the self-energy of a packet of free electron waves which agrees in shape with the bound wave function. Alternative subtraction procedures will be discussed but rejected. One difficulty in the relativistic calculation is that at first sight the level shift seems to be of order αV where $\alpha=e^2/\hbar c$ and V is some average of the potential energy; moreover, this term still diverges logarithmically at high frequency. However, actually the term of order αV vanishes identically because the bound wave function satisfies the Dirac equation. There remain then terms of order $\alpha^2 V$, as in non-relativistic theory. The most important term depends on the wave function at the origin and shifts the s-levels only, but the spin-orbit coupling ($P_{3/2}-P_{1/2}$ splitting) is also changed, and levels like $d_{3/2}$ and $P_{3/2}$ in hydrogen will no longer coincide exactly.

Z9. The Electromagnetic Level Shift. F. J. DYSON, *Cornell University.* (Introduced by H. A. Bethe.)—Following a suggestion of Bethe, the shift of the energy levels of a one-electron atom due to the interaction of the electron with the radiation field has been calculated, using relativistic mechanics but ignoring the spin of the electron. The electron is represented as a particle of spin zero satisfying the relativistic Klein-Gordon wave-equation. Using Bethe's method of subtracting the self-energy of a free particle from that of the bound particle, the calculations give finite values for the level-shifts; owing to a certain arbitrariness in the subtraction prescription, these values are not uniquely defined, but the limits of ambiguity amount to only a small percentage of the predicted shifts. For the $2s-2p_{1/2}$ separation in hydrogen, the most plausible subtraction prescription gives a value of 1034 megacycles, in close agreement with Bethe's non-relativistic estimate and with experimental evidence. The calculations are less formidable than those for a Dirac electron; this is principally because the current operator of a slowly moving Klein-Gordon particle is uniformly small, whereas the Dirac α-operator always gives some matrix elements of magnitude comparable with unity. The quantities to be calculated are expanded in eigen-functions of the Klein-Gordon equation, and the non-orthogonality of these eigen-functions causes much less trouble than was anticipated.

Z10. On the Electromagnetic Shift of Energy Levels. JULIAN SCHWINGER, *Harvard University,* AND VICTOR WEISSKOPF, *Massachusetts Institute of Technology.*—A relativistic calculation of the electromagnetic shift of atomic energy levels, as observed by Lamb,* can be carried out on the basis of the hole theory of the positron. Two different methods are being used whose fundamental idea consists in the elimination of the infinite self-energy either by suitable subtraction of the free electron mass or by modifying the Hamiltonian to unite the electromagnetic mass with the mechanical mass of the electron. The effect of the polarization of the vacuum by the Coulomb field must be included in this calculation; however, the previous treatment of this effect by Uehling did not consider exchange effects. The two methods are equivalent and give

rise to a finite value of the level shifts, the order of magnitude being the same as conjectured by Bethe.**

* Lamb and Retherford, Phys. Rev. **72**, 241 (1947).
** H. A. Bethe, Phys. Rev. **72**, 339 (1947).

Z11. Equations of the Neutrino. NATHAN ROSEN, *University of North Carolina.*—The neutrino, regarded as a particle having zero charge, zero rest-mass, and spin $\frac{1}{2}$, is usually described by means of the Dirac equations. This means that a neutrino field is described by complex functions. However, one would expect a wave field composed of neutral particles to be described by means of real functions. It is found that one can obtain a self-consistent formalism involving only real functions by means of a transformation from the usual Dirac formalism. It appears that, with the description of the neutrino field by means of real functions, one can remove the difficulty in the neutrino theory of light associated with the arbitrariness of the phases of the complex functions used in the past.[1]

[1] M. H. L. Pryce, Proc. Roy. Soc. **A165**, 247 (1938).

Z12. Tensor Forces and the Binding Energy of the Triton. W. RARITA, *Brooklyn College,* AND H. FESHBACH, *Massachusetts Institute of Technology.*—The success of tensor forces in explaining the two body phenomena leads one to hope that the three particle nuclear problems can also be fitted into the theory. An important such problem is the triton binding energy. An initial attack was made by Gerjuoy and Schwinger,[1] using Gaussian wave functions. Instead we have introduced the more flexible Hylleraas expansion for the trial wave function which allows a more systematic improvement of the binding energy sought. Because of the sharp discontinuity in the rectangular potential the variational method here used may not be entirely reliable. Tests of the procedure used were made by applying it to the binding energy problem of the deuteron with tensor forces and also to the binding energy of the triton with a square well potential but without tensor forces. We estimate that the present theory assuming the same range and rectangular shapes for all the potentials will give at most but 60 percent of the experimental triton binding energy. We are investigating the sensitivity of this result to range and potential well shape.

[1] E. Gerjuoy and J. Schwinger, Phys. Rev. **61**, 138 (1941).

Z13. Molecular Systems Containing a Positron. AADNE ORE,* *Princeton University.*—Recently Wheeler[1] has envisaged the existence of atomic or molecular systems which contain a positron, e.g., e^+Cl^-. Since the ordinary approximate methods of molecular or atomic theory are not well adapted to the problem of the dynamic stability of the new systems, information about this stability that can be obtained without elaborate calculations has been sought, (1) from experimental data descriptive of hydrides and molecular hydrogen and, (2) from previous calculations of the energy of light poly-electrons. Procedure (1) corresponds essentially to a variational treatment utilizing exact molecular wave functions. This method is refined by modifying these functions according to the virial theorem. While no molecular wave function is explicitly known the necessary matrix elements can be obtained from available spectroscopic data. The treatment suffices to guarantee stability only when the positron is replaced by a positive meson of mass of the order of twenty electron masses or more. Procedure (2) allows a lowering of these approximate minimum mass values, in a special case (e^+H^-) to a few electronic masses. The results do not exclude the systems envisaged by Wheeler.

* Frank B. Jewett Fellow.
[1] J. A. Wheeler, Ann. New York Acad. Sci. **48**, 219 (1946).

Z14. Light *versus* Matter. GERTRUDE SCHWARZMANN.—The basic difference between the motion of light and that of matter is the independency existing between frequency and speed of light compared to the functional interdependency existing between frequency and speed of material entities. Conjoint to the speed v of electrons and protons are the frequencies $v^2 \cdot b/7.3$ and $252v^2 \cdot b$, respectively, where b stands for $\{(c^2-1^2)/(c^2-v^2)\}^{\frac{1}{2}}$. The speed of light c is an unattainable upper limit of the speed of particles and particle waves as the particle speed c is conjoint to the particle frequency infinite, unattainable upper limit of the frequencies of both, light and matter. From the viewpoint of this paper, based on the same assumptions as "Actual Mass and Inert Mass" in this issue, the mass equivalent to the energy of a produced or materializing photon is on one hand its own inert mass, on the other hand the inert mass of the dematerializing or produced particle pair. The variation of the frequency of material entities with b is prerequisite to a universe built up of four kinds of material entities and to the conservation of linear momentum on materialization and dematerialization respectively.

SUPPLEMENTARY PROGRAMME

SP1. A Precision High Voltage Vacuum-Tube Voltmeter.[1] * LUKE C. L. YUAN, *Princeton University.*—A vacuum-tube voltmeter circuit is described which is capable of measuring voltages within the range of from 0 to -5000 volts with an accuracy of 0.05 percent and a linear characteristic over the entire range. The input impedance is greater than 5×10^{10} ohms. The circuit was developed for the purpose of measuring accurately high voltage sources of extremely low current drain which were employed for cosmic-ray studies. It is based on a null method using a vacuum tube having a high amplification factor as one arm of a balanced circuit and a constant current source as the other arm. The negative terminal of the measured voltage is applied to the plate of the tube and the grid voltage is

varied to maintain the same grid current which balances the current from the constant current source. Linearity results from the negligible varying space-charge effect at constant grid current, and high precision measurements are obtained by means of a special circuit for measuring the change in grid voltage. By setting the grid current equal to a value of $1/\mu$, where μ is the amplification factor of the tube, the meter can be made to read directly the measured voltage.

[1] This work was supported by the Office of Naval Research.
* To be called after Session H if time permits.

SP2. Electronic Polarizability of O^{--} in Presence of Ti^{+4}.* W. SHOCKLEY, *Bell Telephone Laboratories.*—Berberich and Bell[1] demonstrated that the high dielectric constant of TiO_2 does not require enormously high values for either electronic or atomic polarizabilities. However, the electronic polarizability, $\alpha(O^{--})$, is anomalously high in Ti compounds compared to other oxides. If $\alpha(O^{--})$, obtained from $(n^2-1)/(n^2+2)$ by subtracting Pauling's[2] cation values, is plotted *versus* volume per O^{--} ion, then values for Al, Be, Mg, Li, Ca, Sr, and Ba oxides fall near one line; Zn, Cd, and Hg about 20 percent higher and TiO_2 and $CaTiO_3$ about 80 percent higher. Data on dispersion indicates that the high values are not due to a small energy gap, but instead to a large sum of matrix elements; this large sum probably arises from the fact that optical excitation involves wave functions aroung the Ti^{+4} ion which can be made up of eight components involving $3d$, $4s$, and $4p$ of about the same energy, whereas for the other cases only four components such as $4s$, $4p$ are available.

* To be called after Session R if time permits.
[1] L. J. Berberich and M. E. Bell, J. App. Phys. 11, 681 (1940).
[2] L. Pauling, Proc. Roy. Soc. 114A, 181 (1927).

SP3. Reflection and Transmission of Electromagnetic Waves by Thin Curved Shells.* JOSEPH B. KELLER, *New York University.*—The equations and boundary conditions for the determination of the electromagnetic field in an infinite homogeneous medium containing a homogeneous obstacle of different material are transformed into two integro-differential equations for the electric and magnetic fields. These equations contain integrals over the obstacle surface and volume. When the obstacle is a shell of constant thickness the fields are expanded in powers of the thickness. The lowest order terms are just the incident fields, and recursion formulae can be obtained for the higher terms. The first-order terms, which give the field scattered by a thin shell, are obtained as surface integrals involving the incident field. These integrals are evaluated approximately, yielding explicit formulae for the scattered field. From the results the law of reflection is derived for curved shells; geometrical optics is obtained in the limit of zero wave-length; the mirror law, the focal length of a curved shell, and the conditions for the occurrence of point images and foci are deduced; the change of phase at a focus is found; the Rayleigh scattering law is obtained when the wave-length is long, etc. The result is compared with various exact solutions, and with the solutions of geometrical optics and of the Kirchhoff method.

* To be called after Session X if time permits.

SP4. Reflection and Transmission of Electromagnetic Waves by a Spherical Shell.* HERBERT B. KELLER AND JOSEPH B. KELLER, *New York University.*—Exact, explicit expressions are obtained for the field of a radiating periodic point dipole in medium 1 at the center of a spherical shell of medium 2, which is bounded by medium 3. The values of ϵ, μ, σ, and the shell radii are arbitrary. The reflected and transmitted fields are examined in various special cases. When the shell radii become infinite, the thickness remaining constant, the fields agree with those obtained by R. K. Luneberg for the case of plane waves normally incident on a flat plate of medium 2 between media 1 and 3. When the radii are infinite and media 2 and 3 identical, the Fresnel formulae for normal incidence of plane waves on a plane interface between two half-infinite media are obtained. When the radii are finite, media 2 and 3 identical, and $\mu_1=\mu_3$ the results of C. T. Tai are obtained. For finite radii, media 1 and 3 identical, and the shell thickness small compared to a wave-length, the fields check with the approximate results of J. B. Keller for the fields reflected and transmitted by a thin shell of any shape, when his results are specialized to the present case.

* To be called after session X if time permits.

SP5. Actual Mass and Inert Mass.* GERTRUDE SCHWARZMANN.—The corpuscles are pictured as thin rings of mass $m\mu^*$ and radius r^* spinning about one of the rings' diameter as spin axis so that their moments of inertia equal $\frac{1}{2}m\mu^*\cdot r^{*2}$. Interpretation of spin motion as full-fledged motion allows of introducing a kinetic energy of spin equal to that of linear motion of the independent corpuscles and of expressing the units of action (h in the case of matter, $(2h)$ in the case of light) as spin quanta. From these assumptions and those previously listed[1] the following conclusions may be drawn: Today's rest masses of electrons and protons are not their actual masses, but the inert masses of electrons and protons proceeding at velocity 1 cm/sec. The inert masses are quantities of motion, $h\cdot f/v^2$ and $(2h)\cdot f/c^2$ in case of particles and photons, respectively. Attributing to all corpuscles equal radius, to all particles equal mass, to all photons the mass of particle pairs, makes the ratio of the frequency to the linear velocity square the actual bearer of the particular particle nature of materiel entities in both corpuscle and wave state.

* To be called after session Z if time permits.
[1] G. Schwarzmann, Phys. Rev. 72, 536 (1947).

TO BE READ BY TITLE

RT1. The Nature of Low Energy Radiation. BENJAMIN LIEBOWITZ, *350 Fifth Avenue, New York.*—The Birmingham conference last July " . . . made abundantly clear that the fundamental idea essential for further progress in physical theory is still lacking." (Quotation from Pryce, Nature **160**, 628.) I suggest that some currently accepted ideas might be profitably re-examined, particularly the corpuscular concept of radiation. Aside from theoretical difficulties arising from this concept, there is sound experimental evidence against it, for example, the "forgotten" photo-ionization of gases and vapors by *sub*energetic radiation. Furthermore, Schwinger's classical prediction of the betatron light and its recent experimental confirmation support the classical theory of *emission* from free electrons right into the visible region. The nub of the difficulty, therefore, lies in *absorption*. To account for absorption processes I have proposed a *post-concentration* conception according to which radiant energy before absorption is undulatory, i.e., *not* concentrated in "corpuscles"; but it becomes concentrated *after* absorption by rapid interchanges of energy among many electrons which, initially, are only feebly excited by the light. As a result of these interchanges, some electrons acquire sufficient energy to make transitions and/or to escape as photoelectrons. The possibility of such electronic interactions seems already implied in quantum statistics. At present, these remarks apply only to low energies.

RT2. The Effective Path Length through a Vertical Cosmic-Ray Telescope.* ENOS E. WITMER, *University of Pennsylvania*, AND MARTIN A. POMERANTZ, *Bartol Research Foundation.*—Previously reported calculations of the average path length traversed by a cosmic-ray particle through a vertical coincidence counter train have been extended to include the more general case of trays of any dimensions.[1] The earlier results were valid only for cosmic-ray telescopes in which the width of the individual trays was negligible in comparison with the length. Formulas have been obtained for the following distributions of cosmic-ray intensity with zenith angle θ: $\cos^2\theta$, $\cos\theta$, isotropic. From these, families of curves of $\bar{L}/L$ *vs.* l/L, with w/L as parameter have been plotted. Here $\bar{L}$ is the average path length, L is the separation between extreme trays, l is the length, and w the width of a tray. As an example, when $L=l=w$, $\bar{L}/L$ has a value of 1.094 for a $\cos^2\theta$ distribution. Details will be published shortly.

* Supported in part by Office of Naval Research.
[1] E. E. Witmer and M. A. Pomerantz, Bull. Am. Phys. Soc. (November 1947), Houston Meeting, Abstract F10.

RT3. Theory of the Damped Non-Linear Oscillator. M. AVRAMY MELVIN, *Columbia University.* Concrete examples are: loaded viscously damped non-linear springs, heavy gyros, a sliding boulder, avalanche, or skier on icy ground, automatic control systems, here considered more generally than in an earlier paper.* Steady states of zero motion and the approaches to them are described. Within the region of faithfulness to a given equilibrium position, the history of the oscillator is represented by a spiral in the velocity-position plane. This spiral may be bounded between two readily calculable comparison spirals beginning at the same initial point. In this way follow criteria for oscillation and over-damping, and the possible existance of any finite number of oscillations in the transient state of non-linear oscillators. A method is given by which the velocity-position plane may be sectioned into successive characteristic *oscillation number regions*, i.e., from which the number of oscillations to the steady state takes on successive half-integer values. Methods for setting upper and lower bounds of the number of oscillations and times required for the deviation to fall to any desired value are described. Several applications are given.

* M. Avramy Melvin, J. App. Phys. **18**, 704 (1947).

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